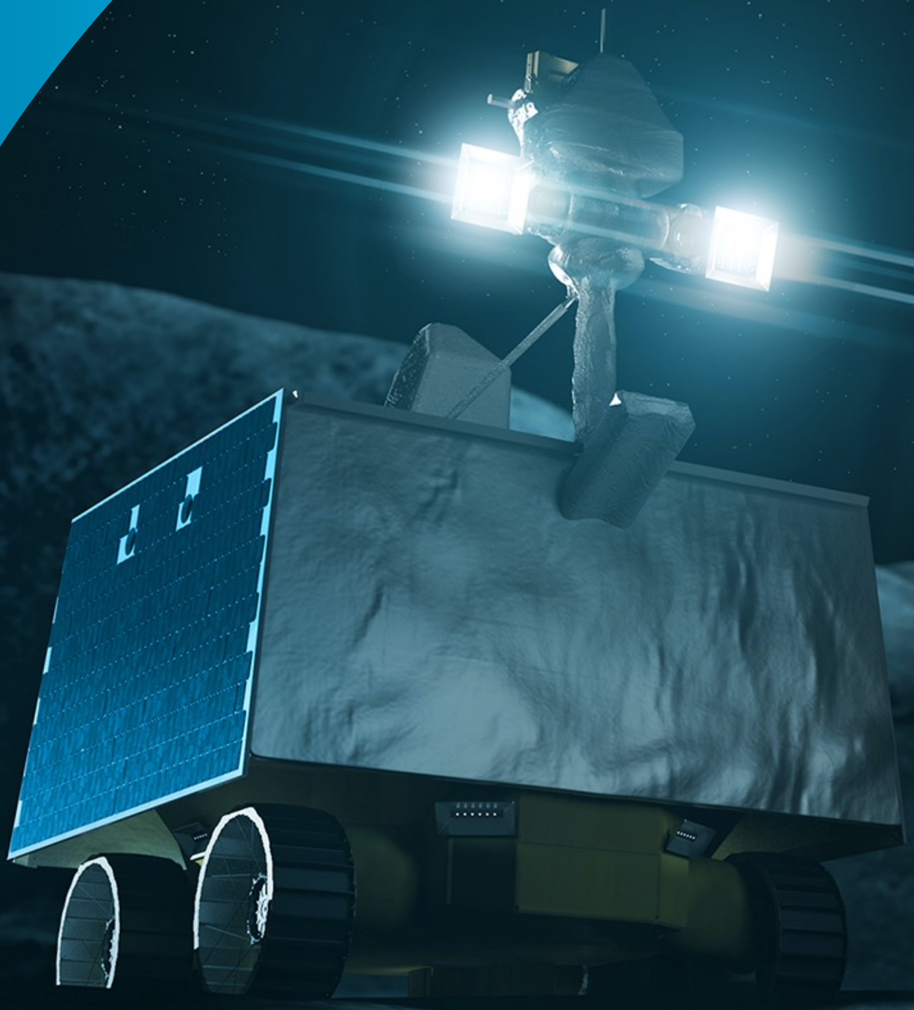
National Aeronautics and
Space Administration



VIPER

Volatiles Investigating Polar Exploration Rover

Mark Rose, VIPER Ground Data Systems
NASA Ames Research Center

January 21, 2022

Just Two Decades Ago…

The Moon was a very different place to how we understand it today…

Studied from the Earth, in-situ and with samples returned to Earth.

The ”general” thinking was:

- Surface was relative constant
- Thin exosphere of Argon, Sodium and Potassium
- Bone dry (~100 ppm of water in soils)

Some believed water could exist on the Moon

1961 JGR

The Behavior of Volatiles on the Lunar Surface[1]

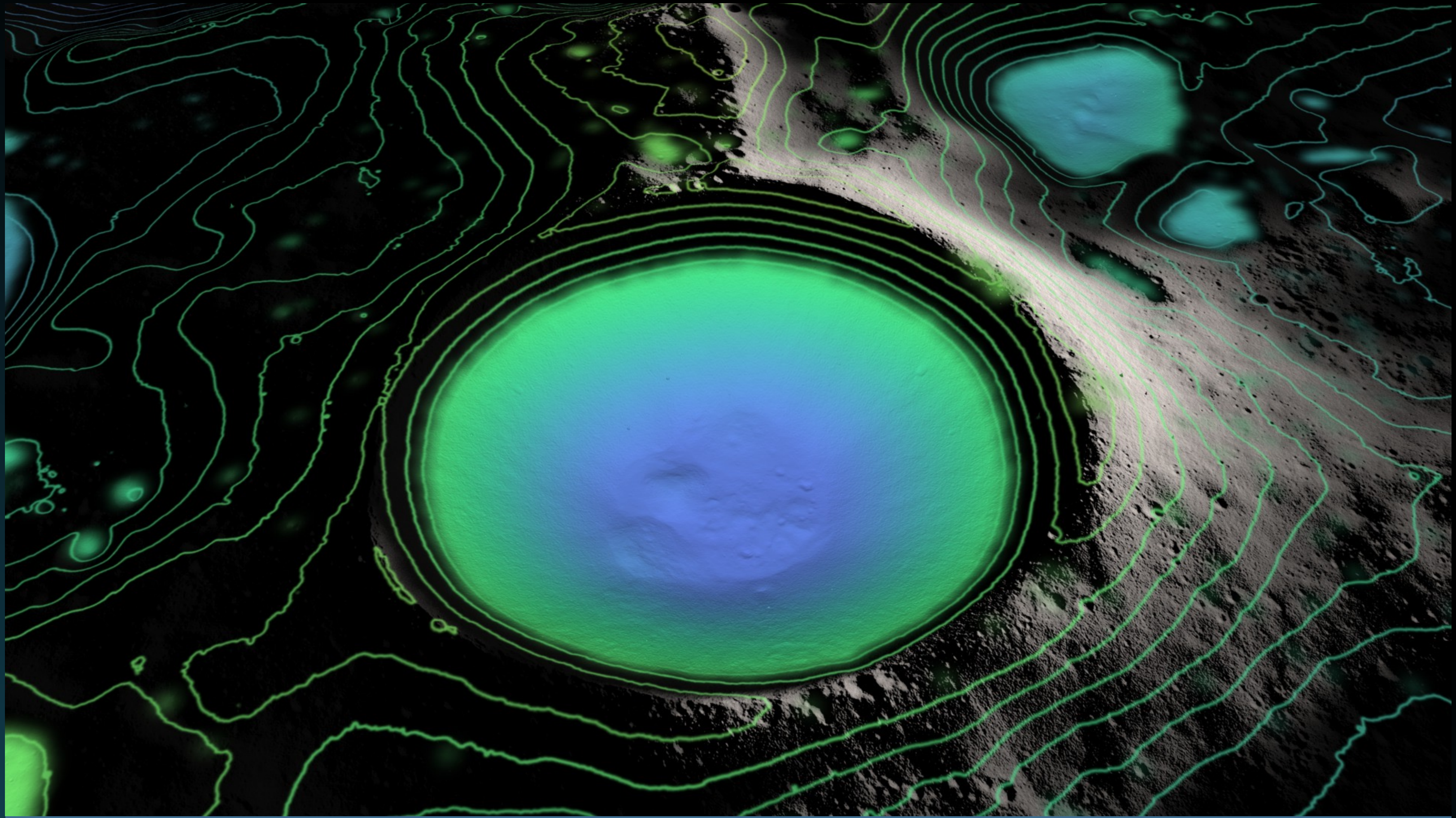
KENNETH WATSON, BRUCE C. MURRAY, AND HARRISON BROWN

Division of Geological Sciences, California Institute of Technology
Pasadena, California

Abstract. Volatiles, and water in particular, have been thought to be unstable on the lunar surface because of the rapid removal of constituents of the lunar atmosphere by solar radiation, solar wind, and gravitational escape. The limiting factor in removal of a volatile from the moon, however, is actually the evaporation rate of the solid phase, which will be collected at the coldest points on the lunar surface. We present a detailed theory of the behavior of volatiles on the lunar surface based on solid-vapor kinetic relationships, and show that water is far more stable there than the noble gases or other possible constituents of the lunar atmosphere. Numerical calculations indicate the amount of water lost from the moon since the present surface conditions were initiated is only a few grams per square centimeter of the lunar surface. The amount of ice eventually detected in lunar 'cold traps' thus will provide a sensitive indication of the degree of chemical differentiation of the moon.

Watson et al. 1961 set expectations that the Moon's poles might hold volatiles including water

Permanently Shadowed Regions (PSRs) on the Moon

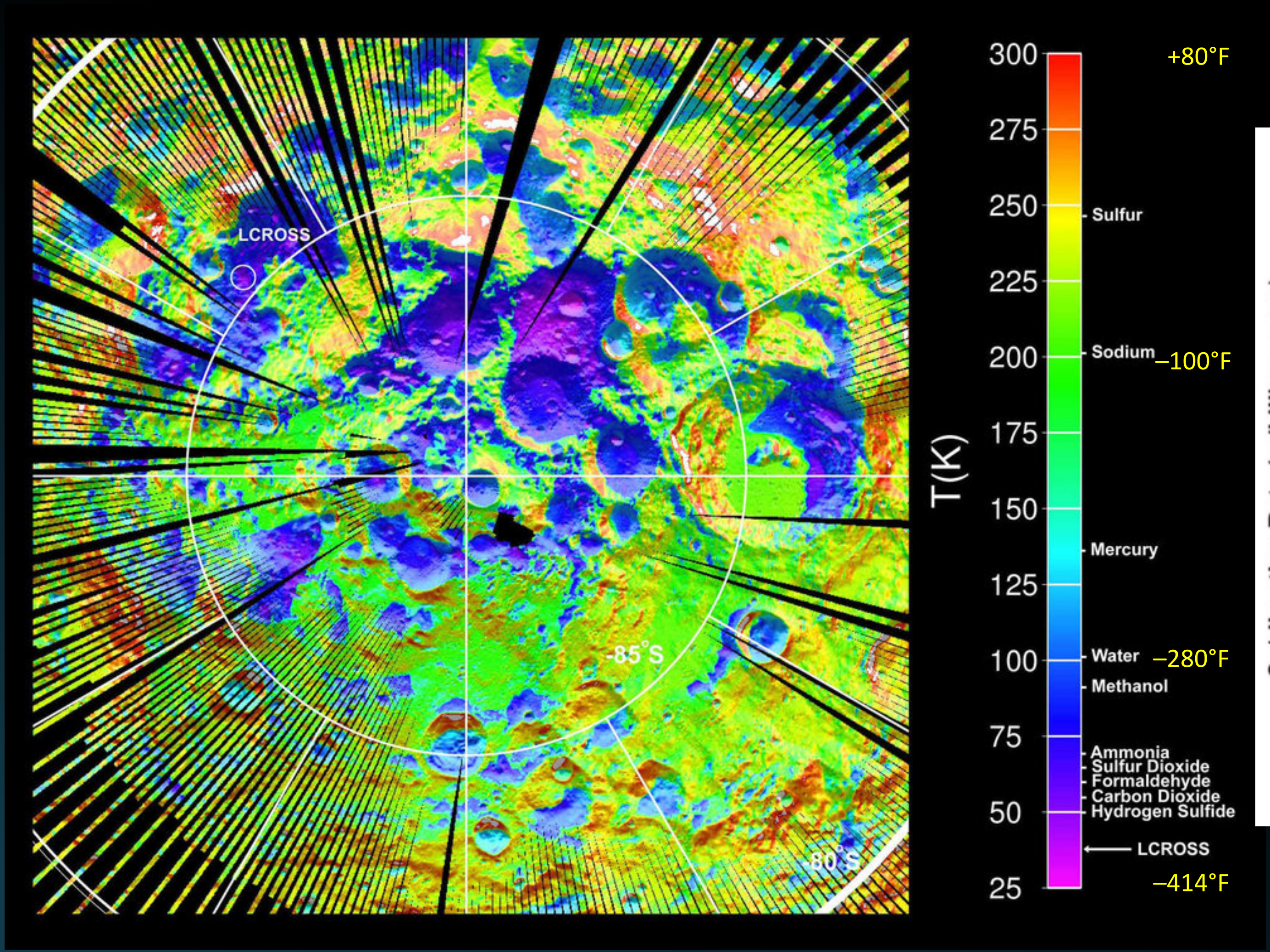


Near the pole, Sun against topography casts long shadows

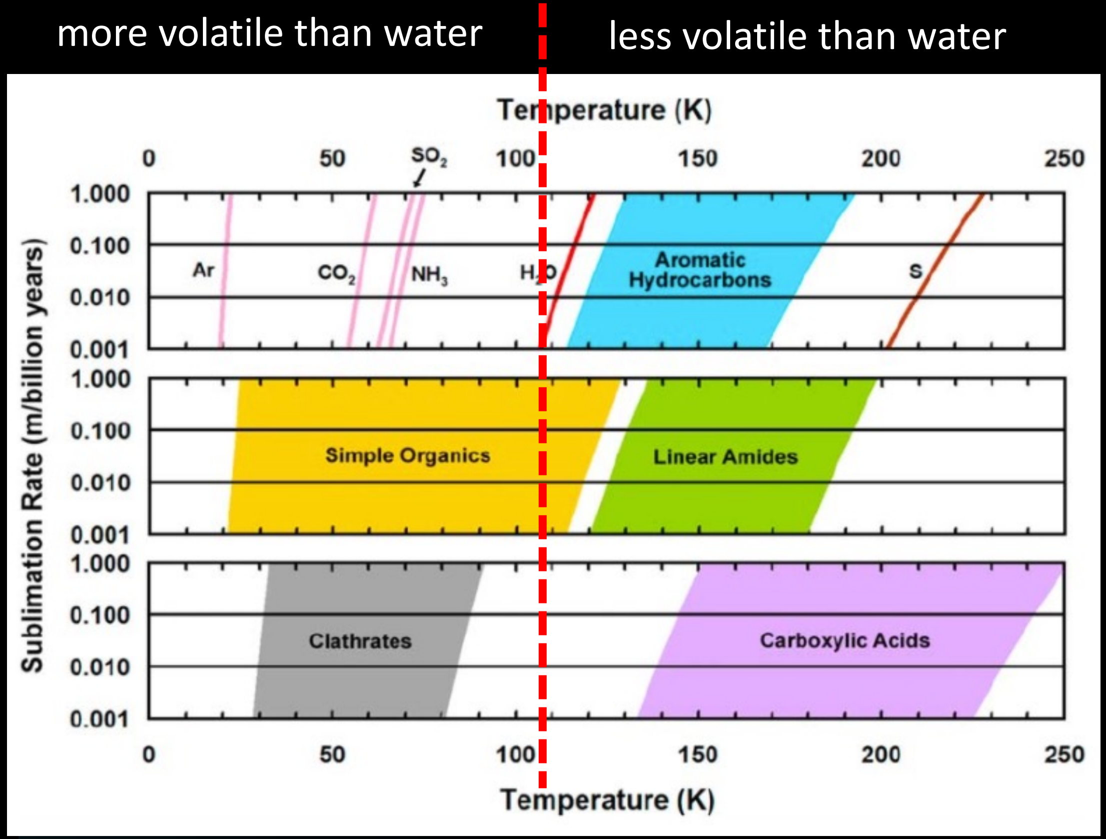
- Low obliquity
- At high latitudes, topography creates permanently shadowed regions
- $>10^4$ km^2 area
- Exist on size scales ranging from the sub-mm (micro) to 10 km

https://svs.gsfc.nasa.gov/4043

Temperature and Volatile Stability



Paige et al. 2010



Zhang & Paige 2009

Clementine (1994):
Bi-static radar tests revealed curious findings at the poles… *Water-ice?*

Lunar Prospector (1998): Neutron measurements reveal shadowed craters contain elevated Hydrogen levels… *Water-ice?*

LCROSS/LRO (2009):
Shadowed Crater Impactor confirms **subsurface water-ice**. *How is the water-ice distributed?*

Chandrayaan-1 (2018):
M^3 instrument confirms **surface ice** at the poles. *How is the water-ice distributed?*

VIPER (2023–2024):
Will prospect for water-ice on human scales, creating water resource maps of the polar regions

The Hunt for Lunar Volatiles

VIPER Science Objectives

National Aeronautics and Space Administration

- Characterize the distribution and physical state of lunar polar water and other volatiles in lunar cold traps and regolith to understand their origin.
- Provide the data necessary for NASA to evaluate the potential viability of In-Situ Resource Utilization (ISRU) from the lunar polar regions.

VIPER will make those desired surface (and subsurface) water ice measurements

Resource Mapping

Sufficiently characterize an area to evaluate the resource potential and/or physical processes that govern distribution

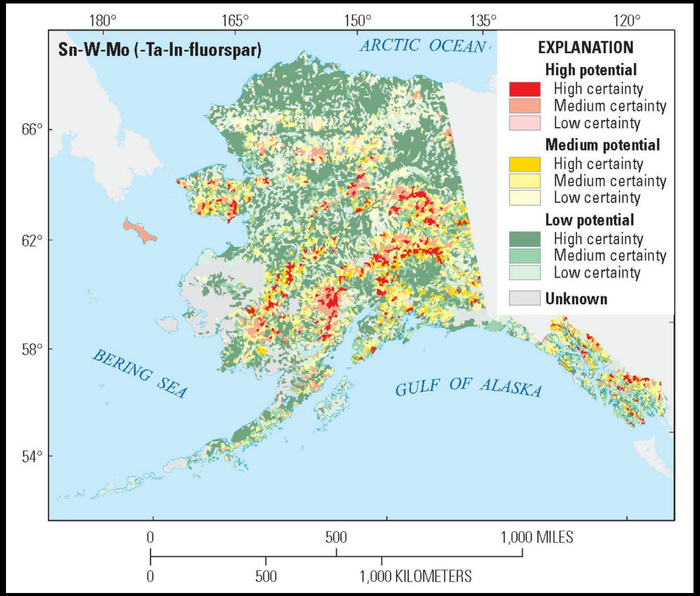
- Terrestrial mining companies develop “Mineral Models” for production evaluation
- The “Mineral Model” for lunar water is uncertain, but the same techniques can be applied

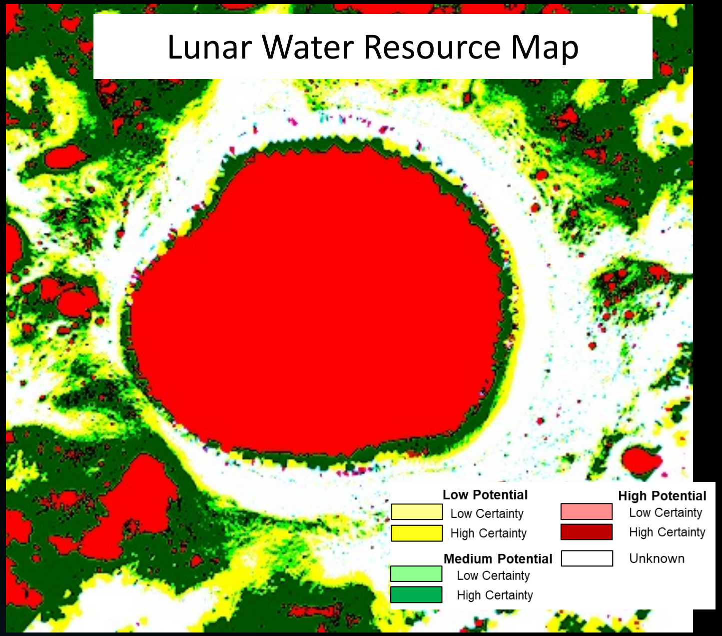
Demonstrated (e.g., USGS) Methods to Characterizing a Resource

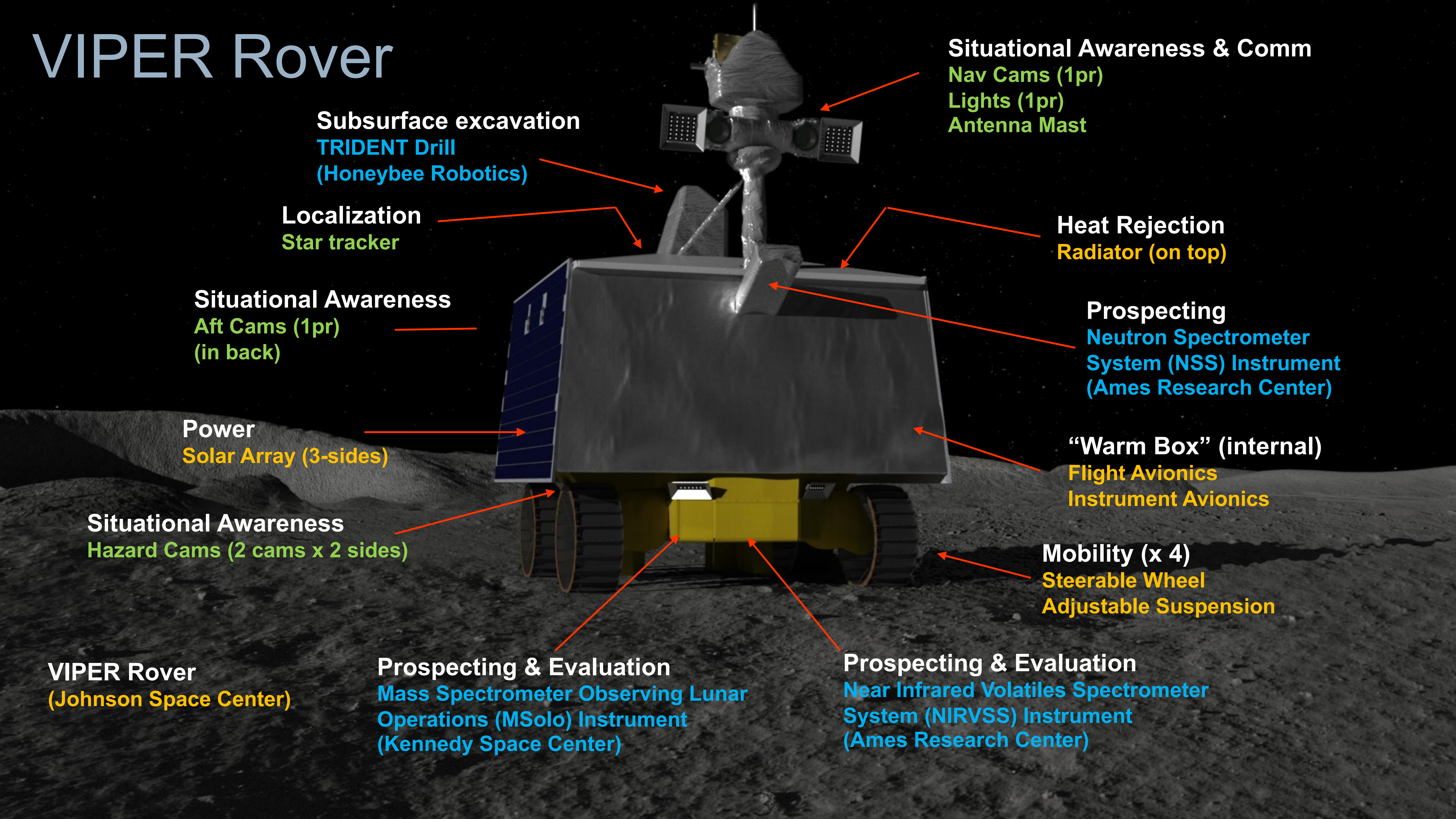
- Gather data – map where the materials are
- Explore spatial variability – horizontal and vertical distribution
- Develop and test empirical and theoretical models and validate

Requirements for the mission

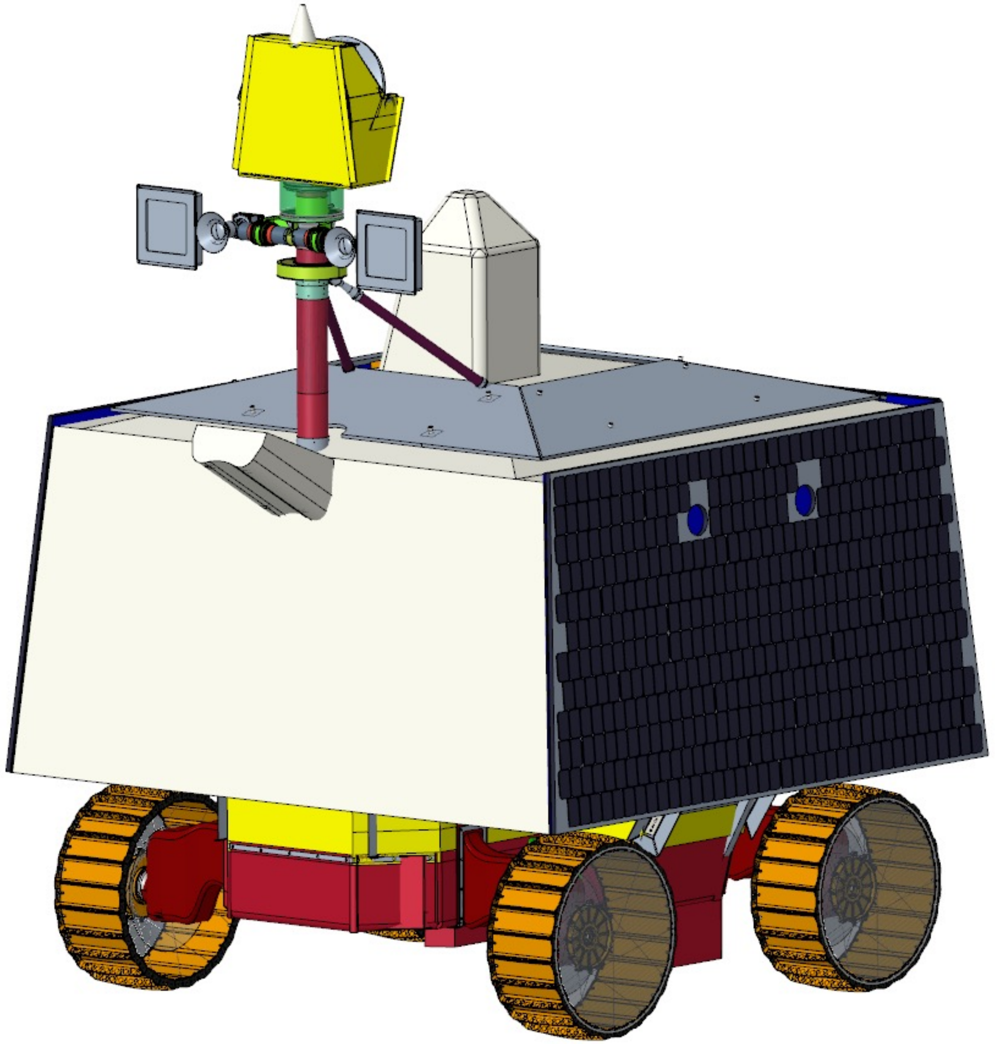
- Wide-ranging mobile rover, with (relatively) fast speed
- Instruments that can detect water and other volatiles while driving
- Ability to sample the subsurface
- Need to survive for weeks, through communication loss and darkness

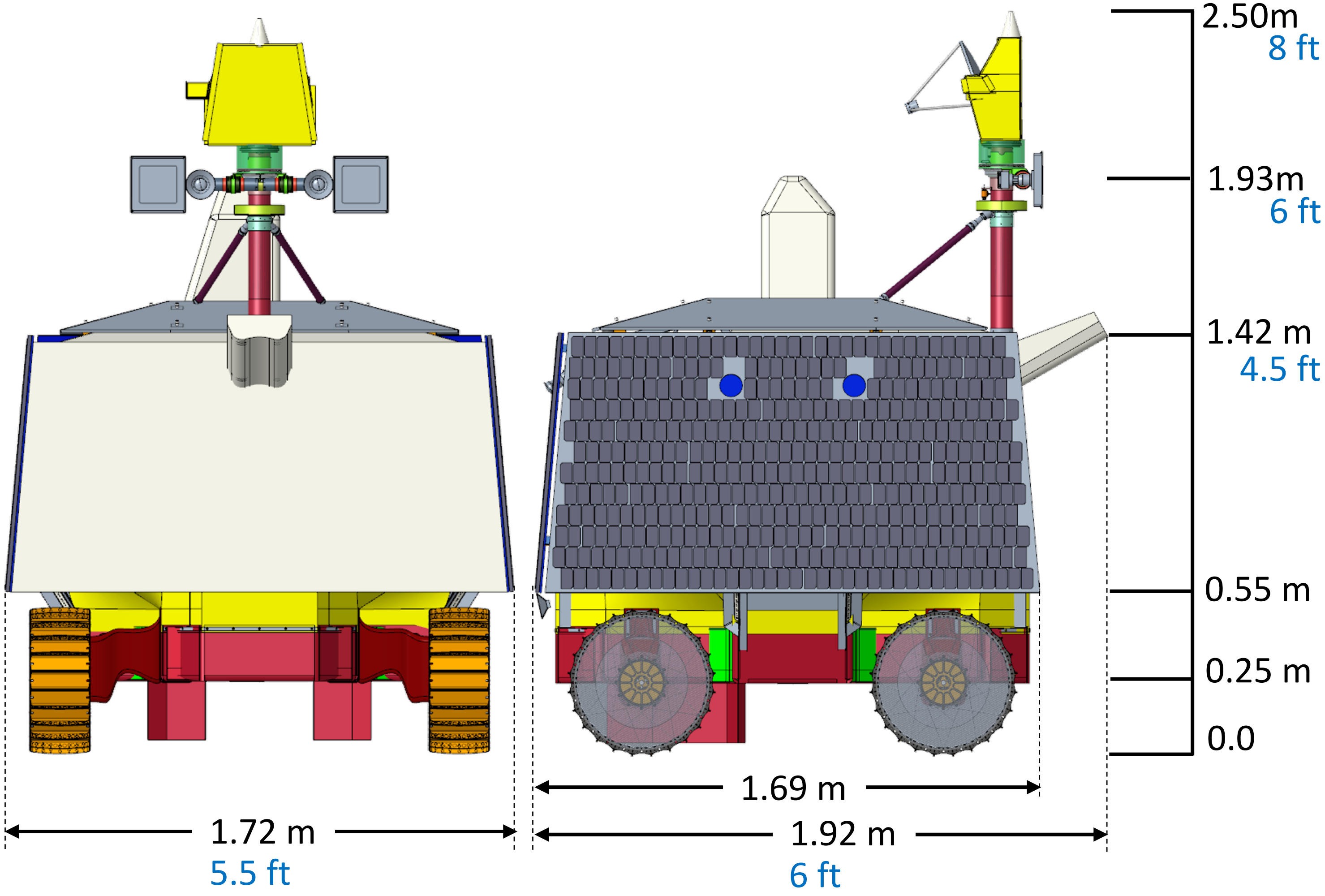





VIPER Rover
Subsurface excavation
TRIDENT Drill
(Honeybee Robotics)
Localization
Star tracker
Situational Awareness
Aft Cams (1pr)
(in back)
Power
Solar Array (3-sides)
Situational Awareness
Hazard Cams (2 cams x 2 sides)
VIPER Rover
(Johnson Space Center)
Prospecting & Evaluation
Mass Spectrometer Observing Lunar
Operations (MSolo) Instrument
(Kennedy Space Center)
Situational Awareness & Comm
Nav Cams (1pr)
Lights (1pr)
Antenna Mast
Heat Rejection
Radiator (on top)
Prospecting
Neutron Spectrometer
System (NSS) Instrument
(Ames Research Center)
“Warm Box” (internal)
Flight Avionics
Instrument Avionics
Mobility (x 4)
Steerable Wheel
Adjustable Suspension
Prospecting & Evaluation
Near Infrared Volatiles Spectrometer
System (NIRVSS) Instrument
(Ames Research Center)

Current Integrated Rover Design





NASA CLPS program has selected Astrobotic Technology to deliver VIPER to the lunar South Pole in late-2023 aboard their Griffin Lander

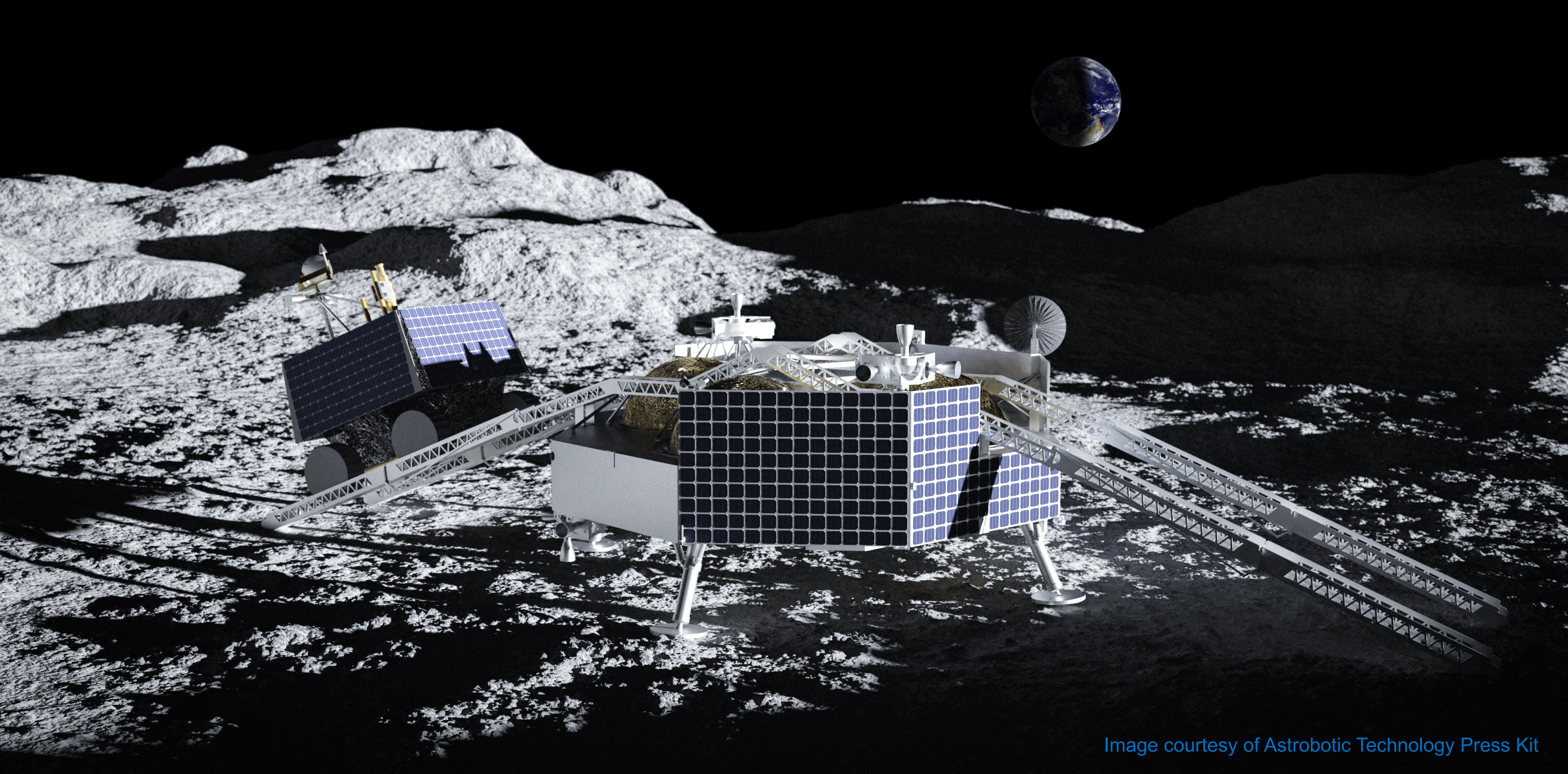
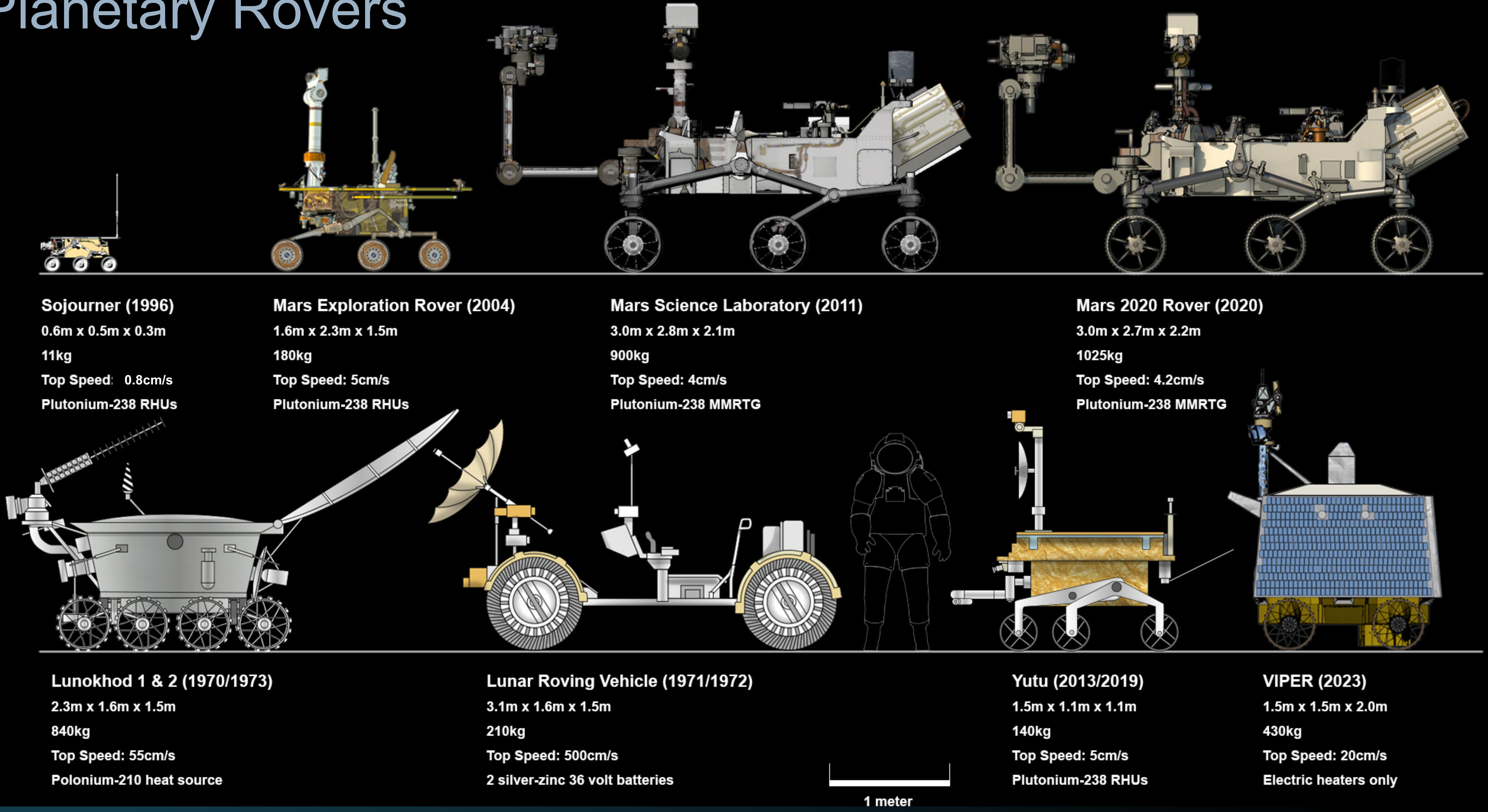
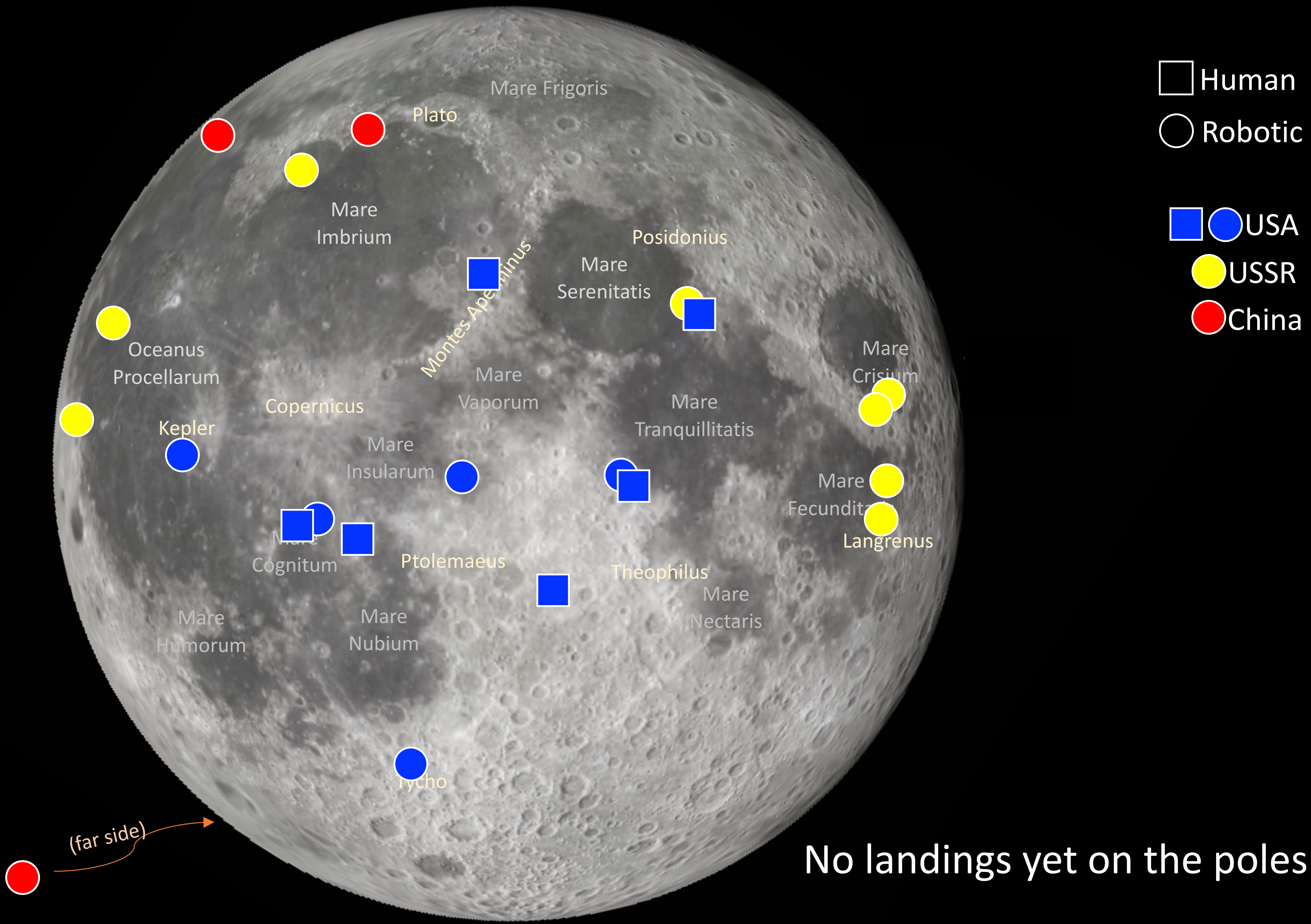


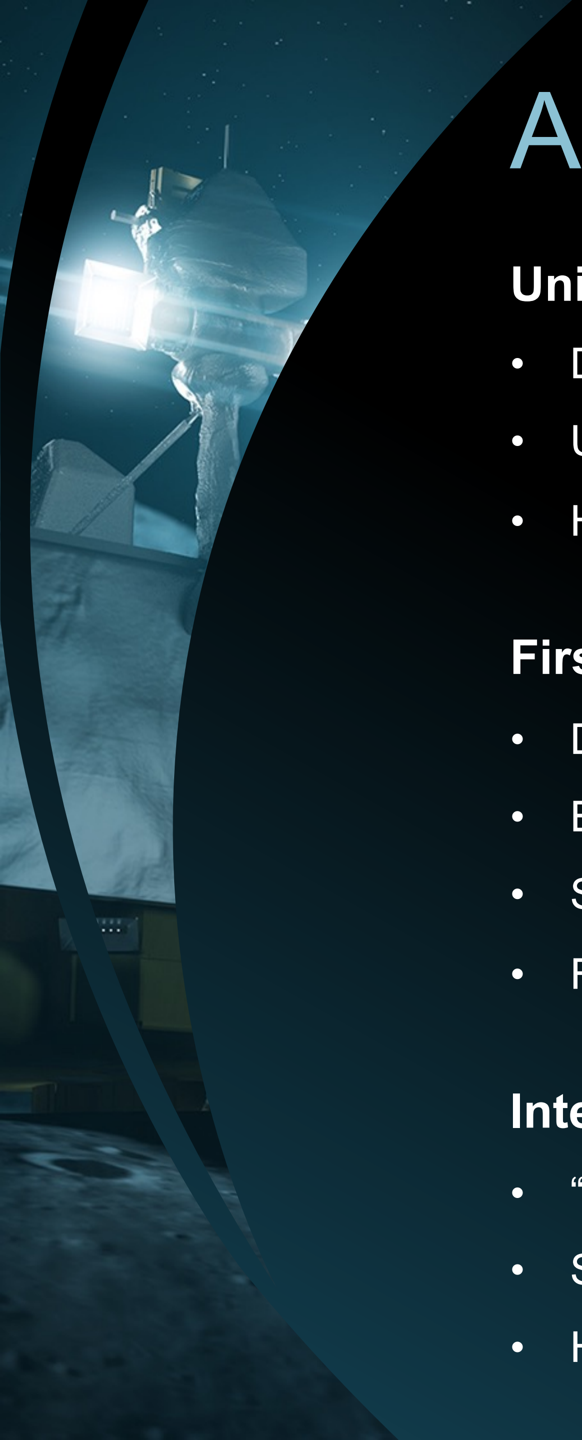
Image courtesy of Astrobotic Technology Press Kit

Planetary Rovers





No landings yet on the poles



A New Type of Planetary Rover

Unique challenges

- Demanding lighting environment – sharp contrasts, long shadows
- Uncertain lunar pole “trafficability”
- Highly variable temperatures – ~40K (–390F) in PSR, to 300K (+80F) in sun

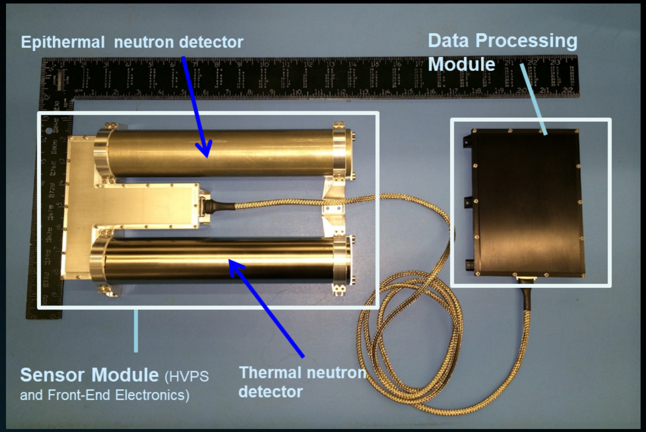
First NASA lunar rover

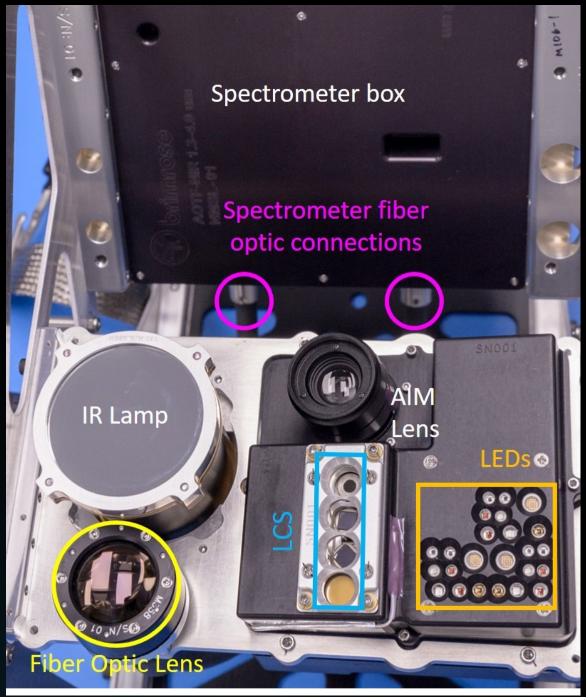
- Designed for the “dynamic” lunar environment
- Emphasis on high operational cadence and traverse speed
- Significantly lower cost than Mars rovers (but higher risk)
- Flight software split between on-board and ground

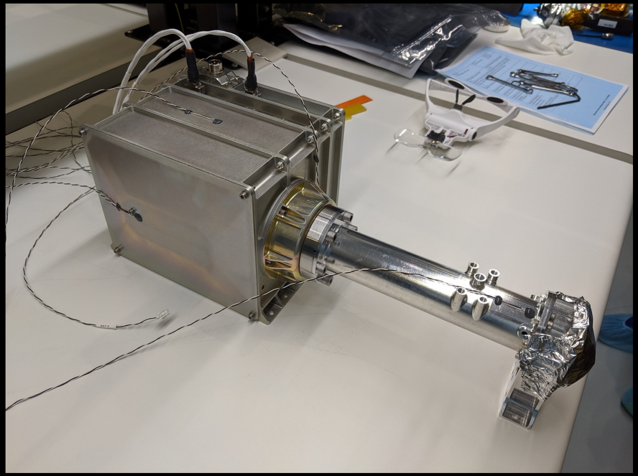
Interactive operations

- “Real-time” mission control – rover operations + science team
- Single waypoint driving (approx. 4m / command cycle)
- Hybrid of human exploration and Mars rover concepts of operations

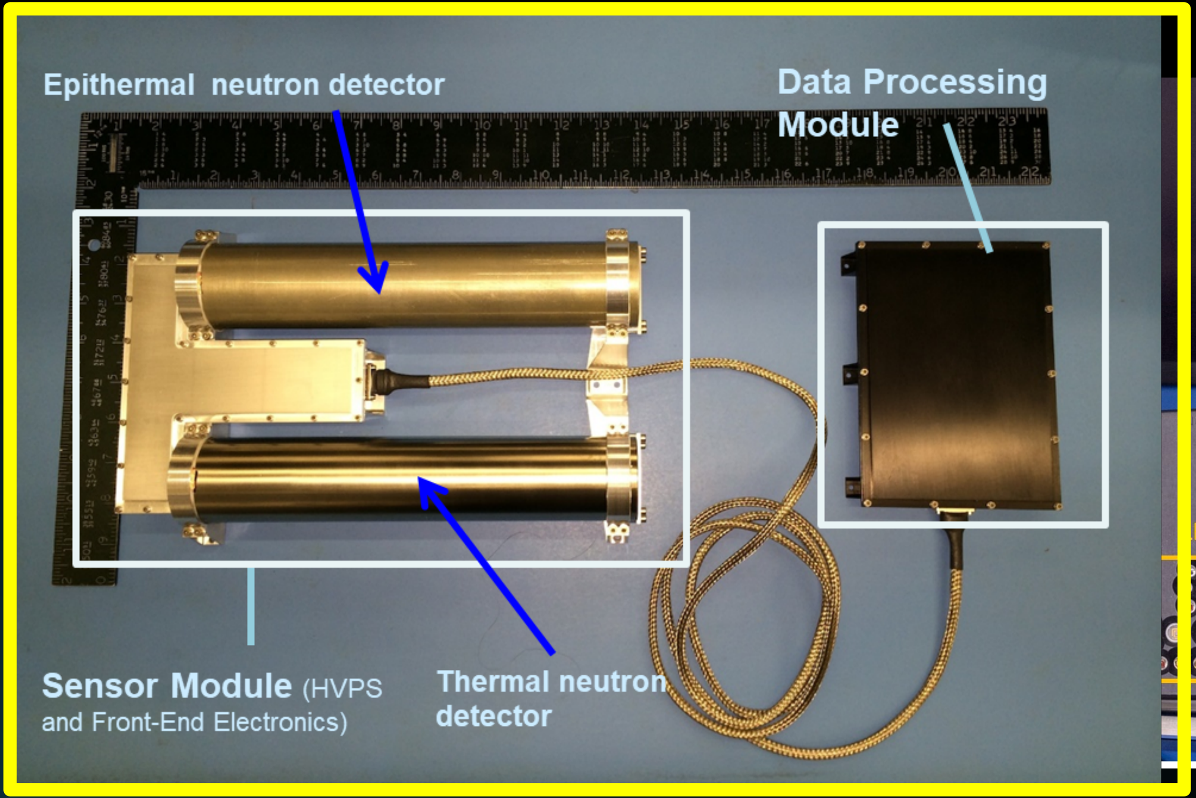
VIPER Science Payload

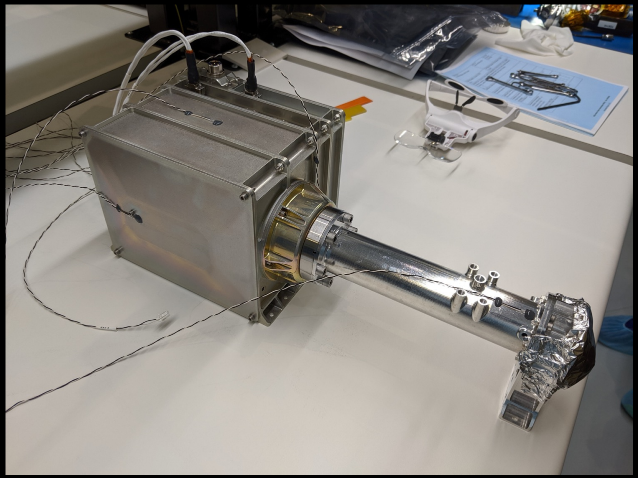






VIPER Science Payload

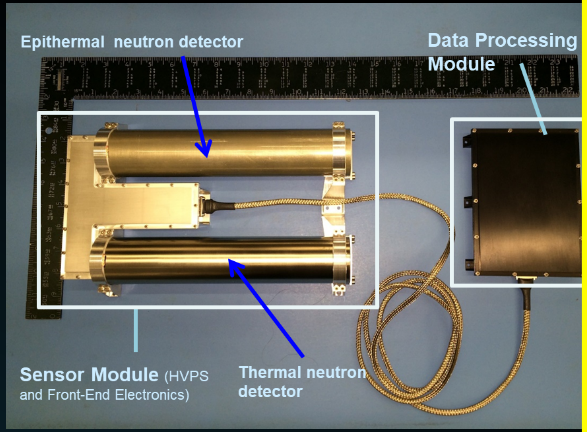


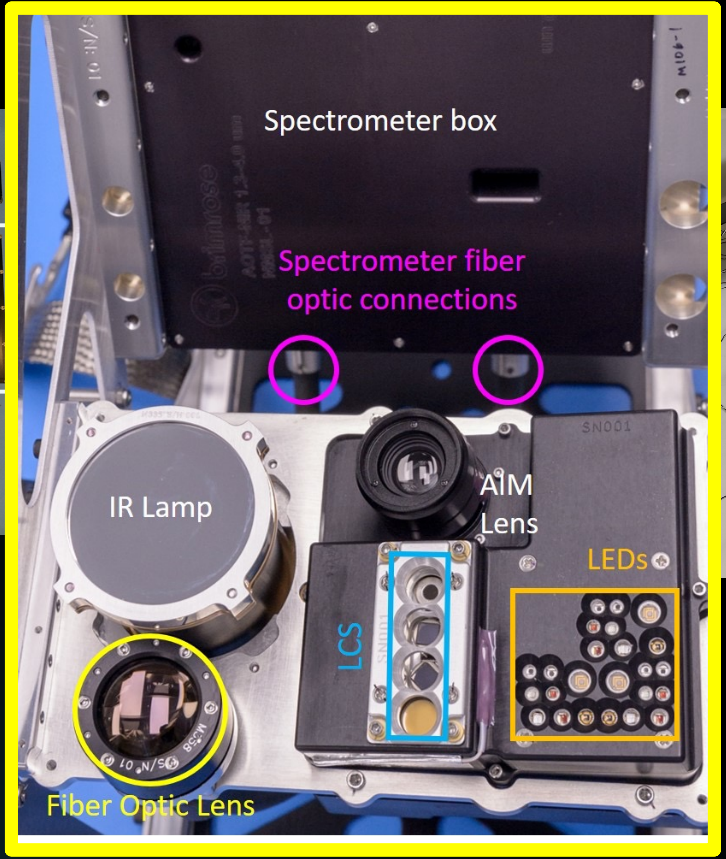


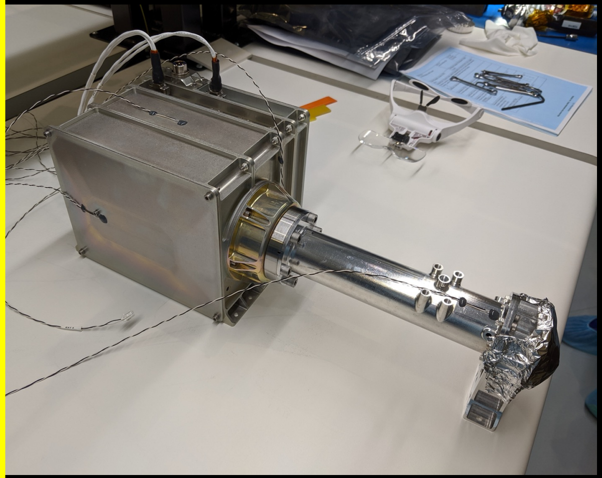
Neutron Spectrometer System (NSS)

- **NASA Ames Research Center, Lockheed Martin ATC**
- **Instrument Type:** Two channel neutron spectrometer
- **Key Measurements:** Assess hydrogen and bulk composition in the top meter of regolith, measuring down to 0.5% (wt) WEH to 3σ while roving

VIPER Science Payload



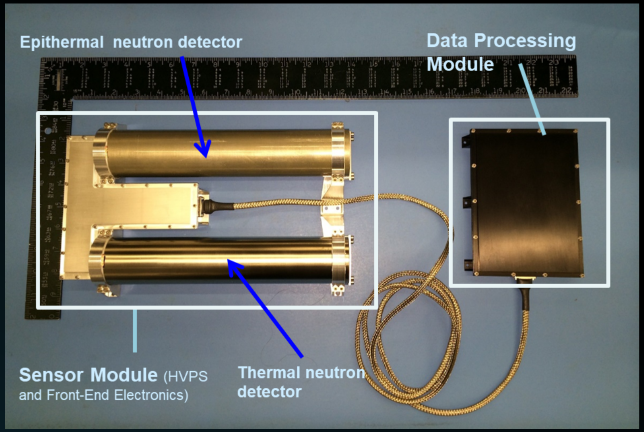


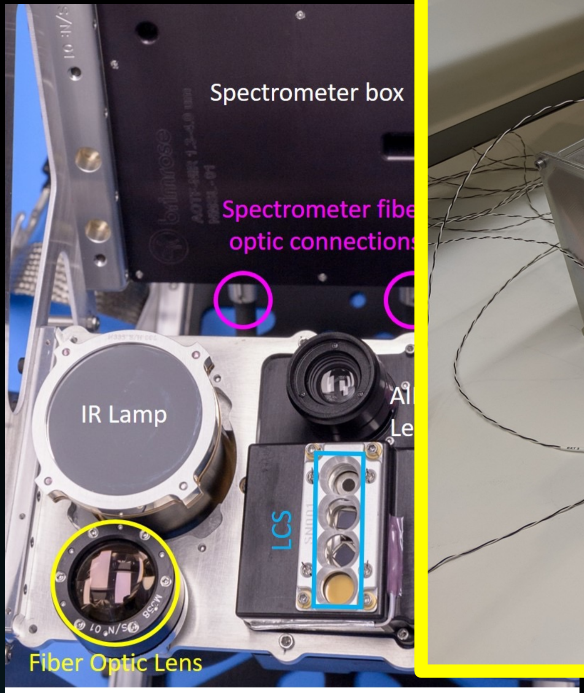


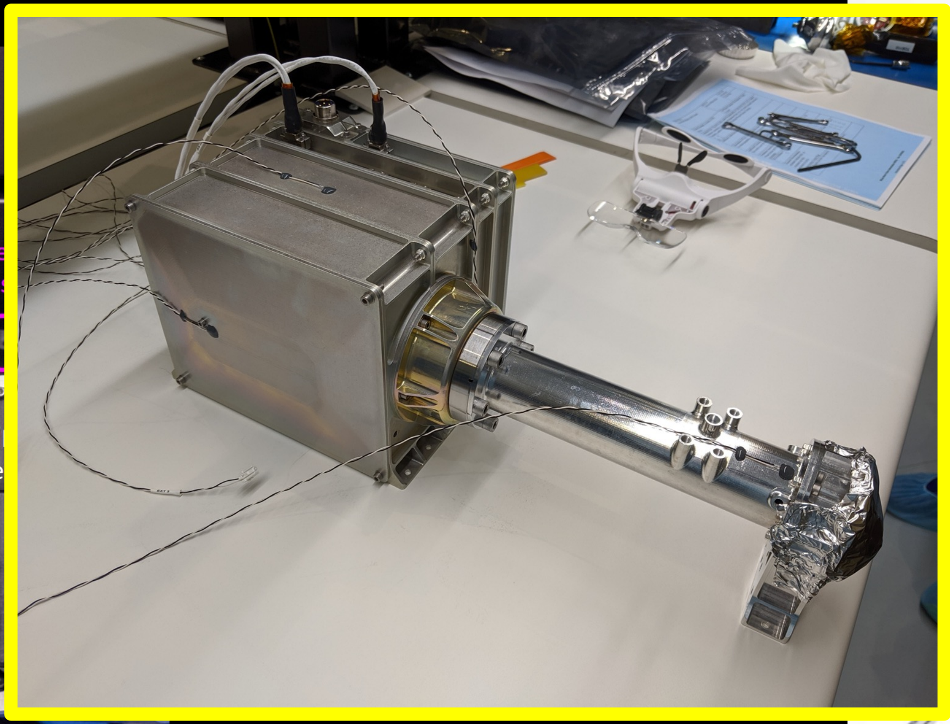
Near Infrared Volatiles Spectrometer System (NIRVSS)

- **NASA Ames Research Center, Brimrose Corporation**
- **Instrument Type:** NIR Spectrometer (1200-4000 nm), 4Mpxl visible imager with 7 color LEDs, four channel thermal radiometer
- **Key Measurements**: Volatiles including H_2O, OH, NH_3, H_2S and CO_2, mineralogy, surface morphology and temperatures

VIPER Science Payload



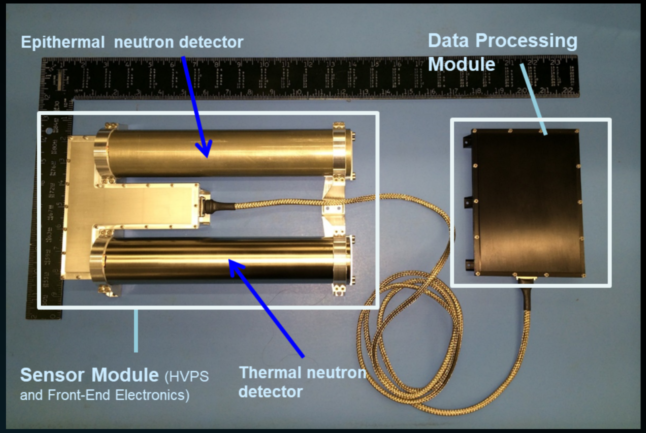


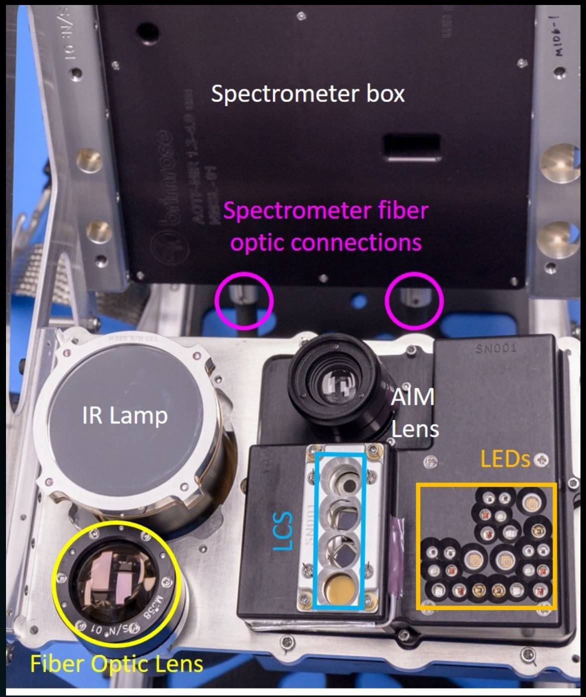


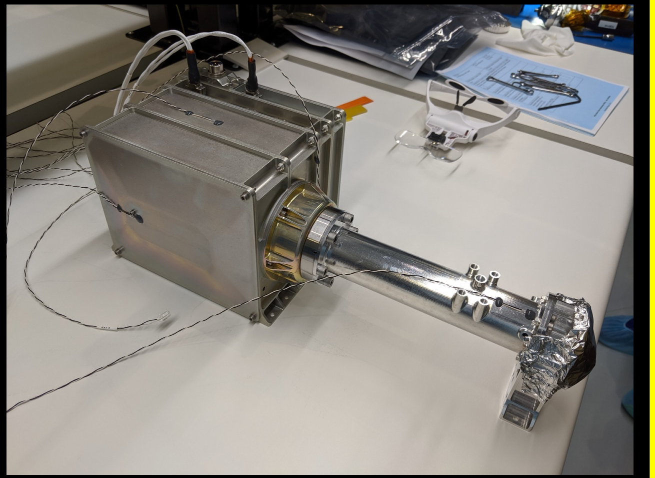
Mass Spectrometer Observing Lunar Operations (MSolo)

- **NASA Kennedy Space Center, INFICON**
- **Instrument Type:** Quadrupole mass spectrometer
- **Key Measurements**: Identify low-molecular weight volatiles between 1-100 amu, unit mass resolution to measure isotopes including D/H and O^{18}/O^{16}

VIPER Science Payload





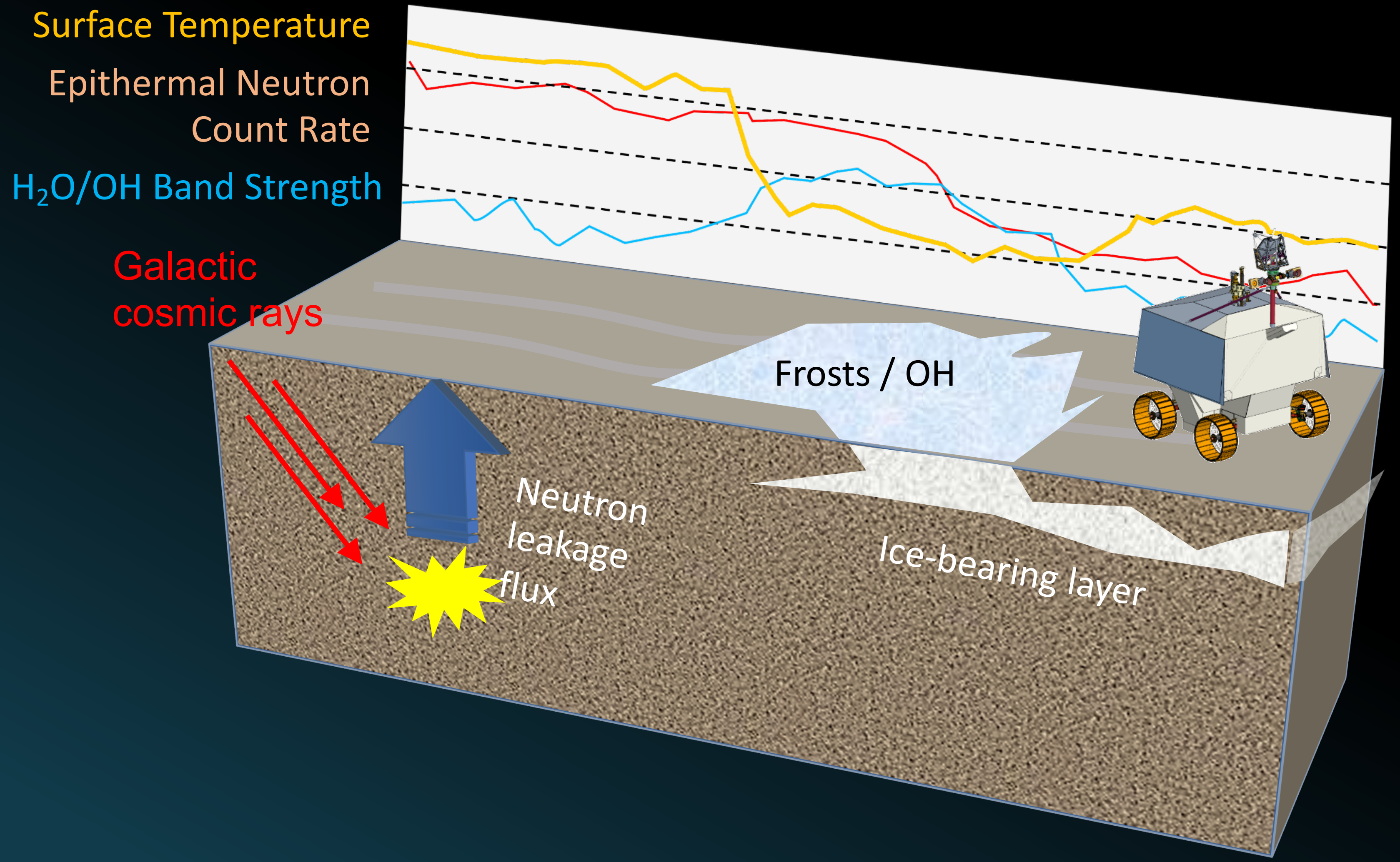


The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT)

- **Honeybee Robotics**
- **Instrument Type:** 1-meter percussive drill
- **Key Measurements**: Excavation of subsurface material to 100 cm, subsurface temperature vs depth, strength of regolith vs depth (info on ice-cemented ground vs. ice-soil mixture)

Prospecting & Subsurface Activities (drilling)

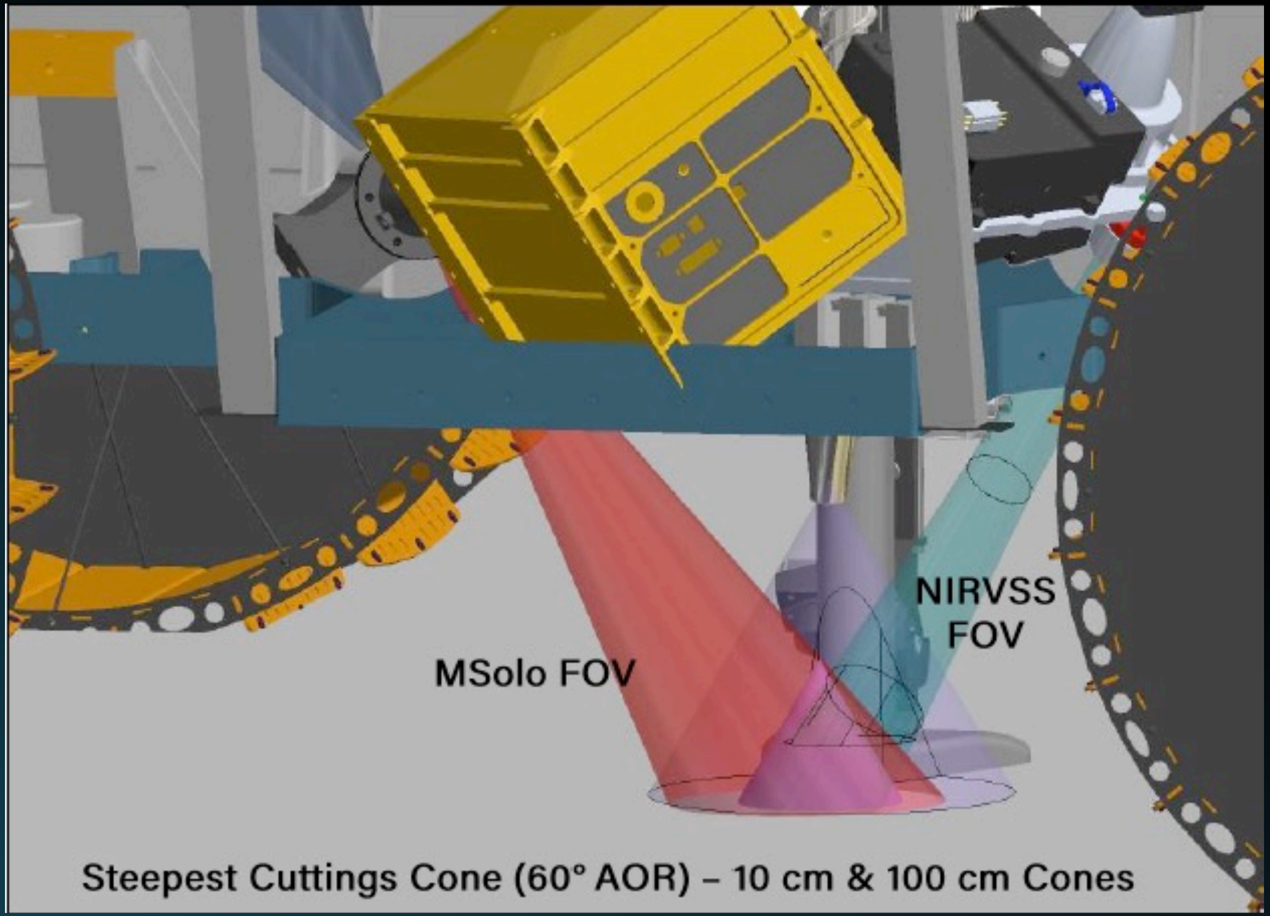
Prospecting: NSS, NIRVSS & MSolo



- NSS, NIRVSS & MSolo take data continuously while roving or parked
- NSS Neutron flux variations identify abundance and burial depth of hydrogenous materials
- NIRVSS NIR surface reflectance identifies surface and excavated hydration
- MSolo detects subliming gasses (H_2 or H_2O vapor) identify surface and excavated hydration
- TRIDENT excavates subsurface materials/ice

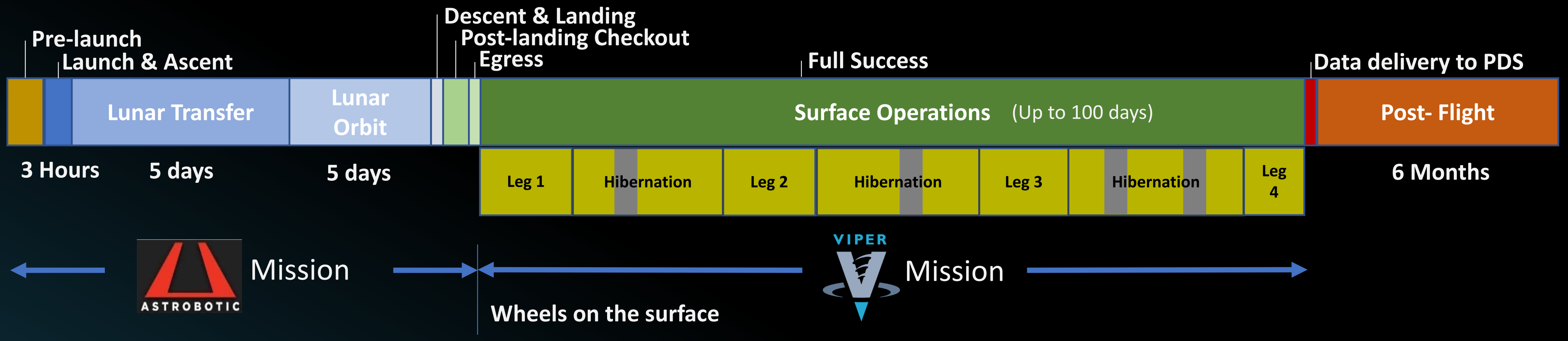
Sampling: TRIDENT, NIRVSS and MSolo

Sampling via the TRIDENT, MSolo and NIRVSS profile water
(and other volatiles with depth, tying down NSS derived concentrations)



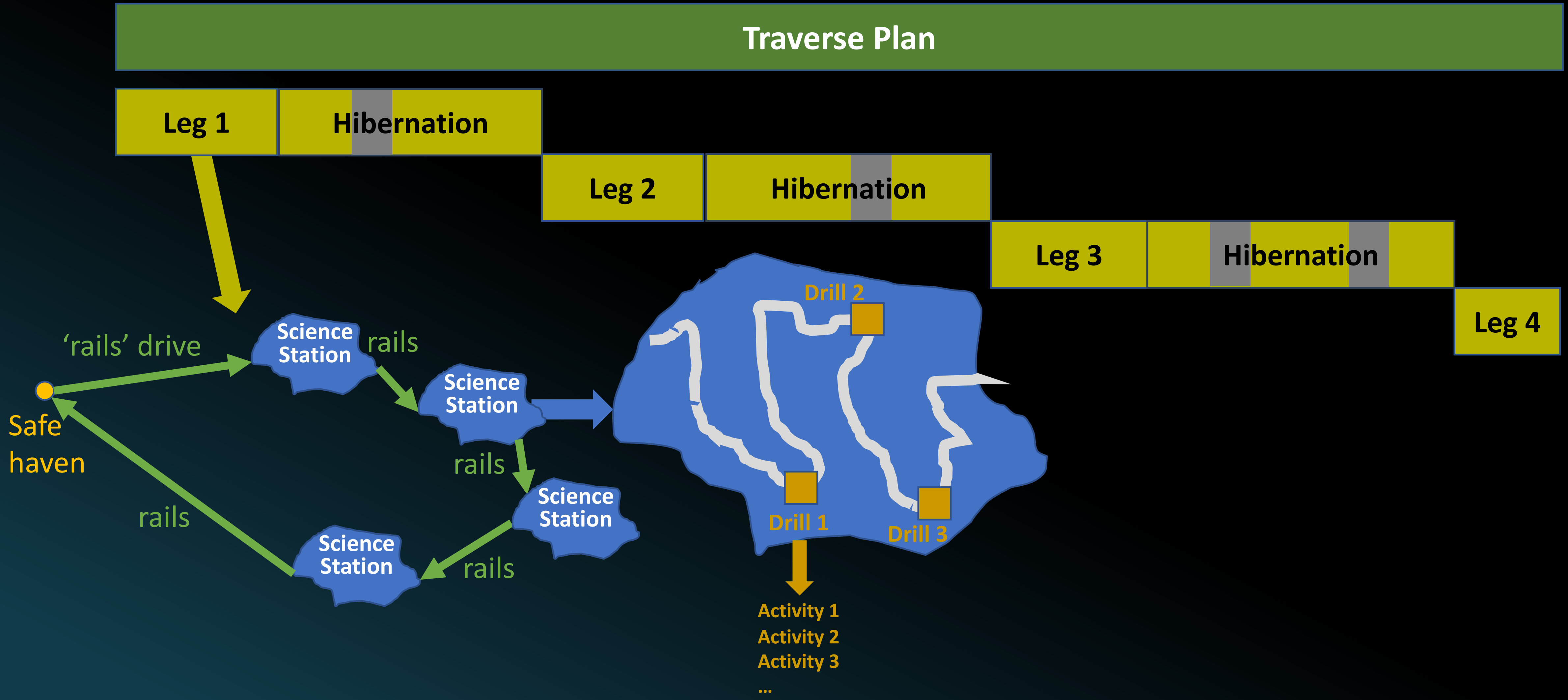
- TRIDENT samples in 10 cm “bites” down to 1 meter, using a simple auger bit
- Each 10 cm sample can be brushed to the surface for inspection by NIRVSS and MSolo
- NIRVSS images the cuttings at multiple wavelengths (providing context for NIRVSS and MSolo observations) and measures the scene temperature
- This process identifies the stratification of hydrogen bearing volatiles, “tying down” NSS measurements

VIPER Mission Phases



- Surface Ops consist of periods of activity ("traverse legs") and periods of inactivity ("hibernations")
    - Traverse legs are in view of Earth and sun (except for planned shadow (PSR) ops (<8 hours))
    - Hibernations are NOT in view of Earth, but in view of sun, with periods of sun shadow (<72hrs)
    - Lunar Day (28 days) = one Traverse Leg + one Hibernation

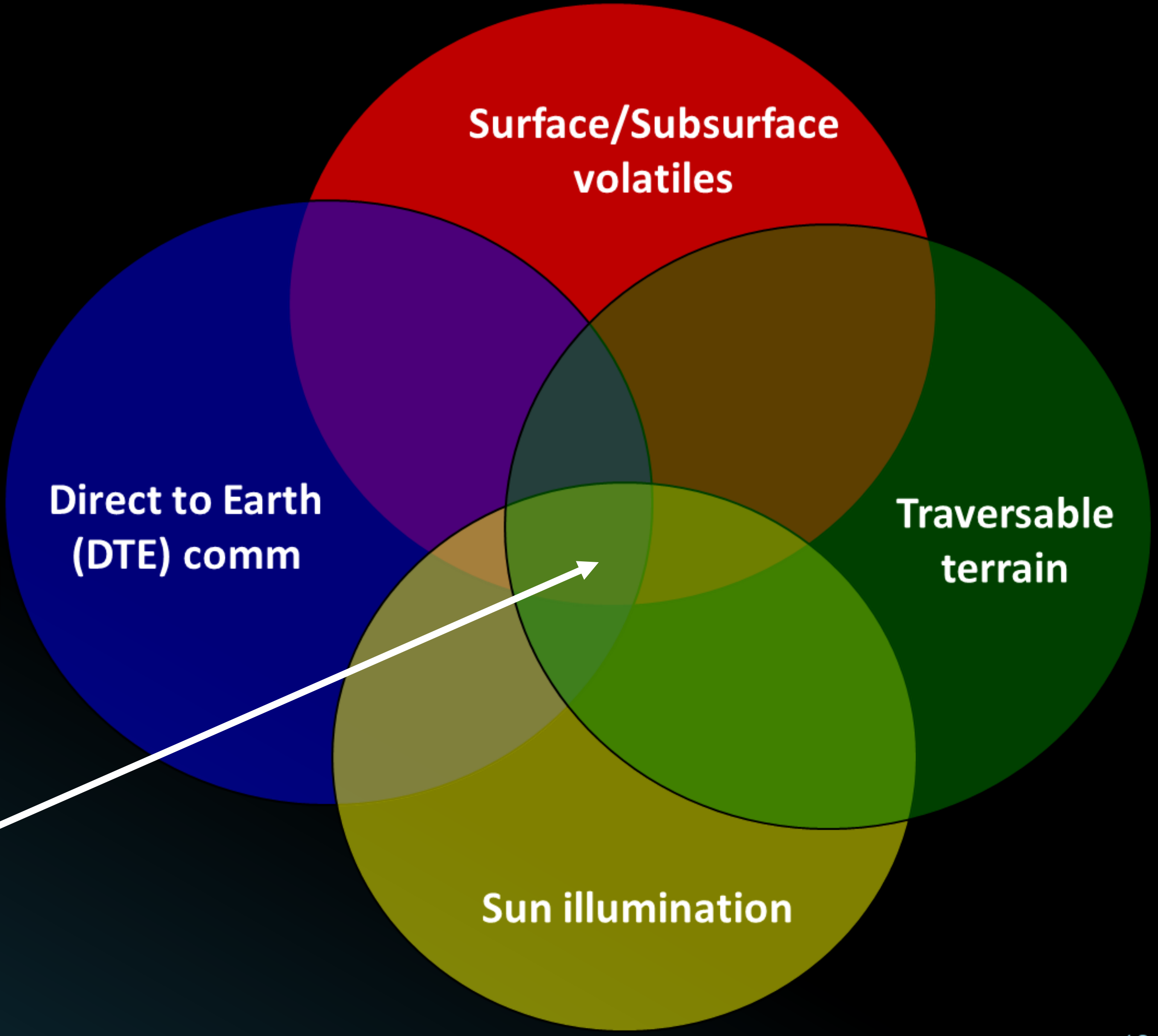
VIPER Surface Operations



Landing Site Requirements: Where are We Going?

Candidate polar landing sites meet these four criteria:

1. Plausible surface/subsurface volatiles
2. Reasonable terrain for landing and traverse
3. Direct view to Earth for communication
4. Sunlight for power



VIPER needs to find the intersection of these constraints

Three locations for traverse studies

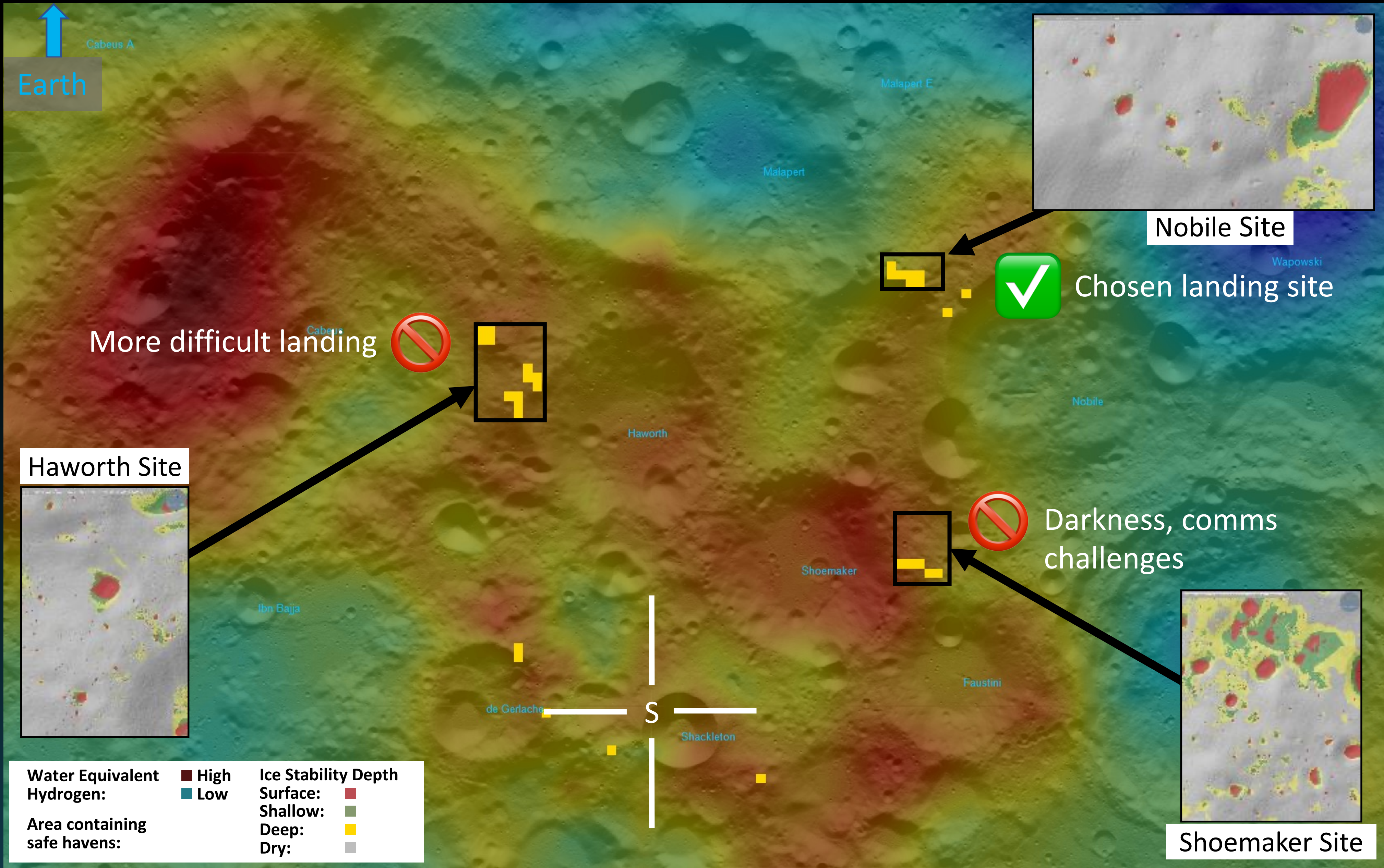
Needed: locations with …

High water-equivalent hydrogen (background map)

A variety of thermal environments using ice stability depth as an indicator (insets)

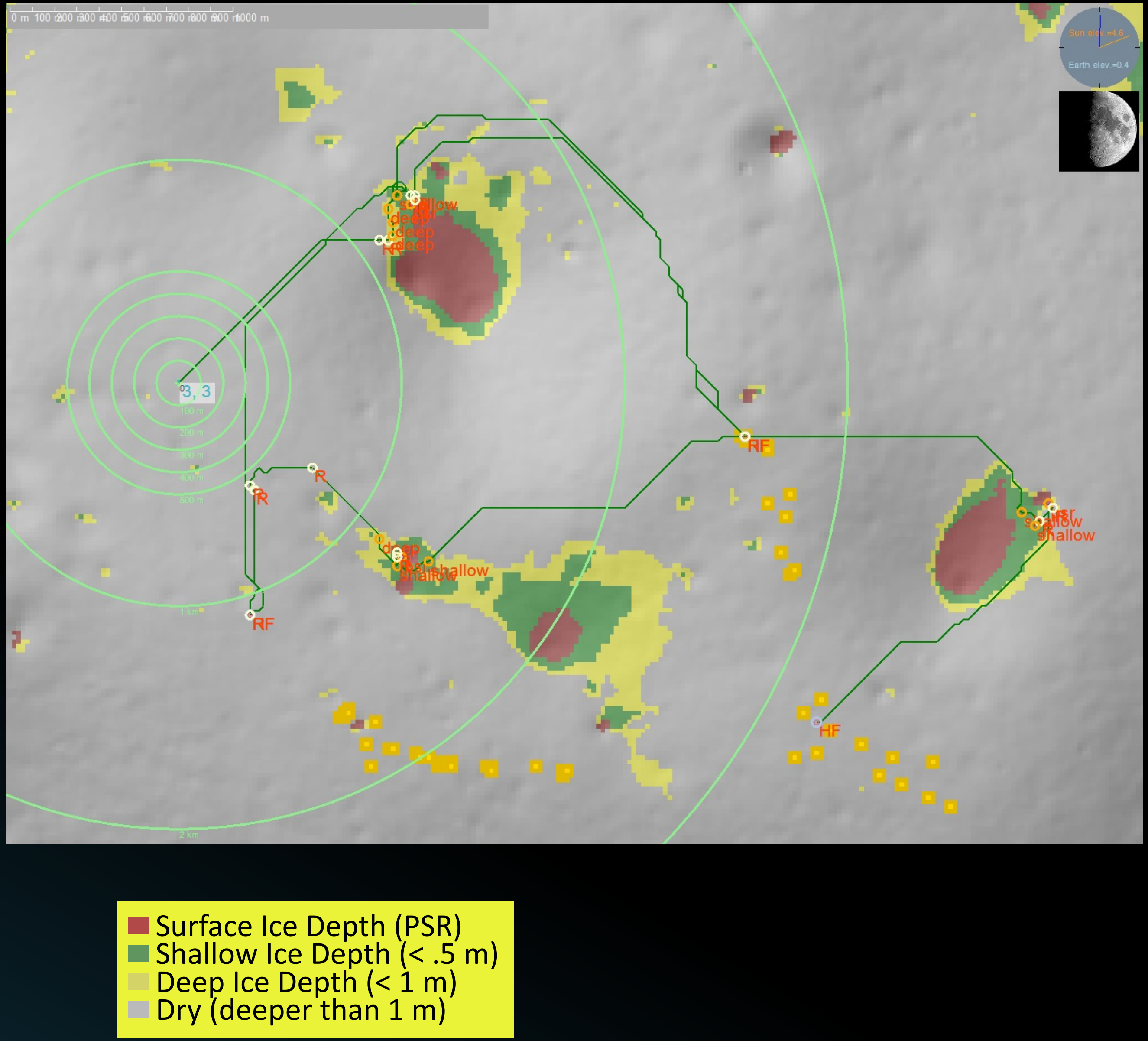
Periods of shadow short enough for the rover to survive (yellow blocks)

Unobscured line-of-site to Earth for communications



Sample Nobile Traverse

<table>
<tr><th>Key Parameter</th><th colspan="3">Value</th></tr>
<tr><td>Launch Date (est)</td><td colspan="3">3 pm 11/10/2023 (all times UTC)</td></tr>
<tr><td>Lunar transfer duration</td><td colspan="3">5 days</td></tr>
<tr><td>Lunar Orbit Insertion (est)</td><td colspan="3">10:45pm 11/15/2023</td></tr>
<tr><td>Lunar orbit duration</td><td colspan="3">7 days</td></tr>
<tr><td>Landing time</td><td colspan="3">8 am 11/23/2023</td></tr>
<tr><td>Total mission duration</td><td colspan="3">106 days + option for 28 more</td></tr>
<tr><td>Surface mission duration</td><td colspan="3">94 days + option for 28 more</td></tr>
<tr><td>Active days on the surface</td><td colspan="3">45 days + option for 10 more
(but limited science)</td></tr>
<tr><td>Landing location</td><td colspan="3">85.449452S, 31.064135E</td></tr>
<tr><td>Average slope at landing site</td><td colspan="3">5º</td></tr>
<tr><td>Light and comm at landing site</td><td colspan="3">12 days</td></tr>
<tr><td>Total driving distance</td><td colspan="3">4.4 km prospecting, 27.4 total</td></tr>
<tr><td>Max distance from landing site</td><td colspan="3">3 km</td></tr>
<tr><td rowspan="2">Science Stations</td><td rowspan="2">12</td><td>2 psr</td><td>4 shallow</td></tr>
<tr><td>4 deep</td><td>2 dry</td></tr>
<tr><td>Full mission success reached</td><td colspan="3">Day 37, near end of 2nd lunar day</td></tr>
<tr><td>Driving Speed</td><td colspan="3">0.813 cm/s normal
0.613 cm/s sunward</td></tr>
</table>



Nobile Traverse Animation

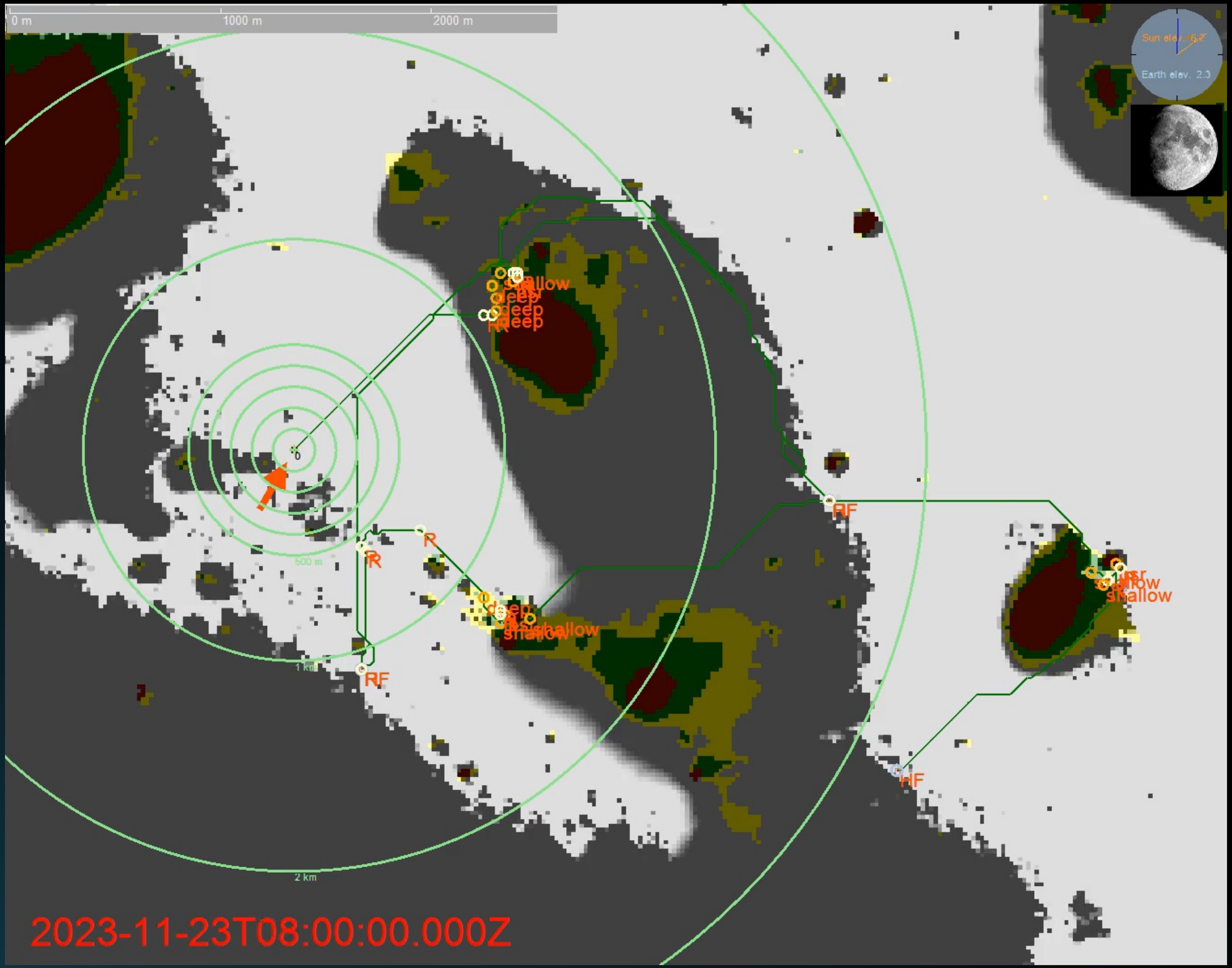
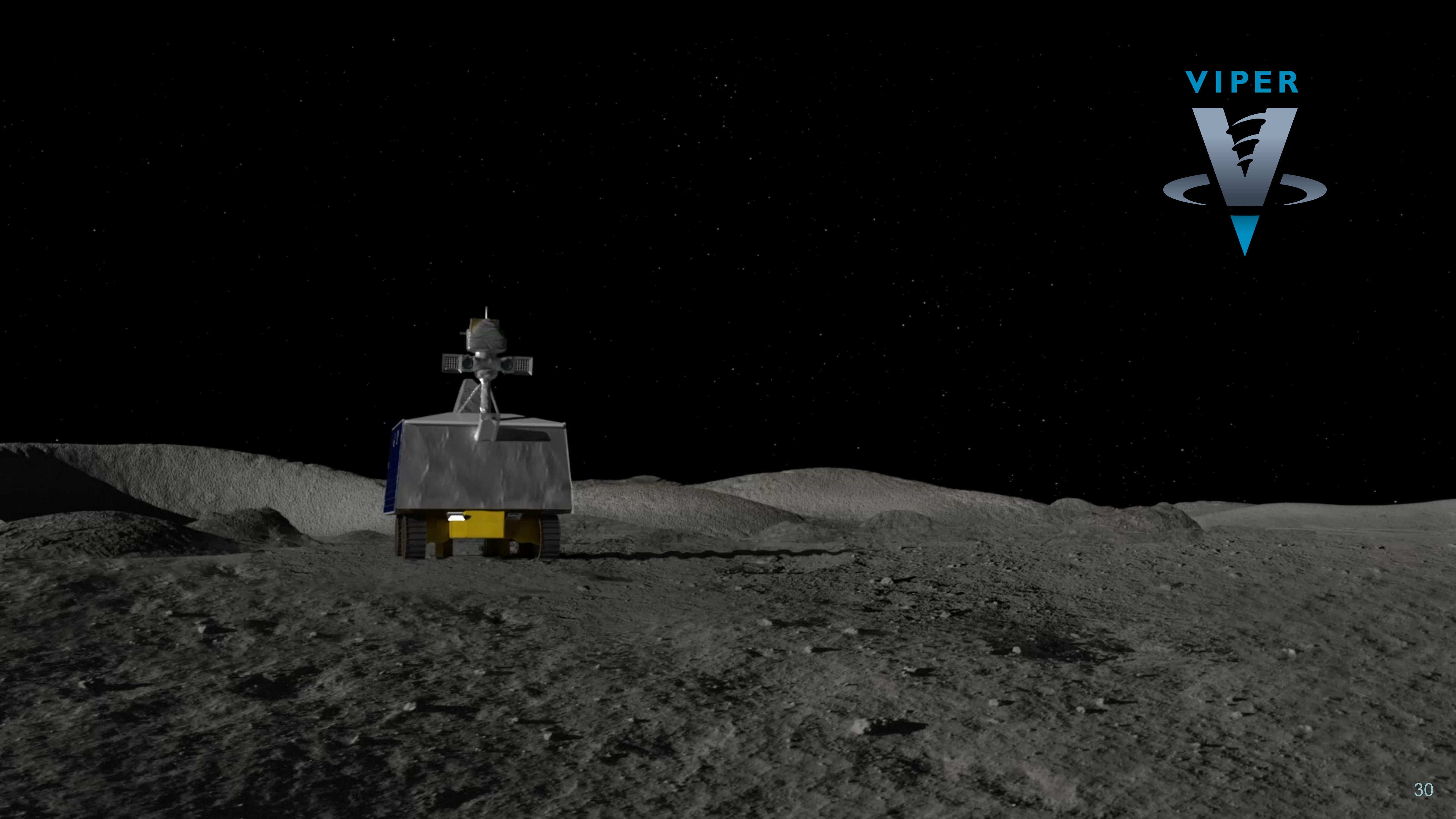
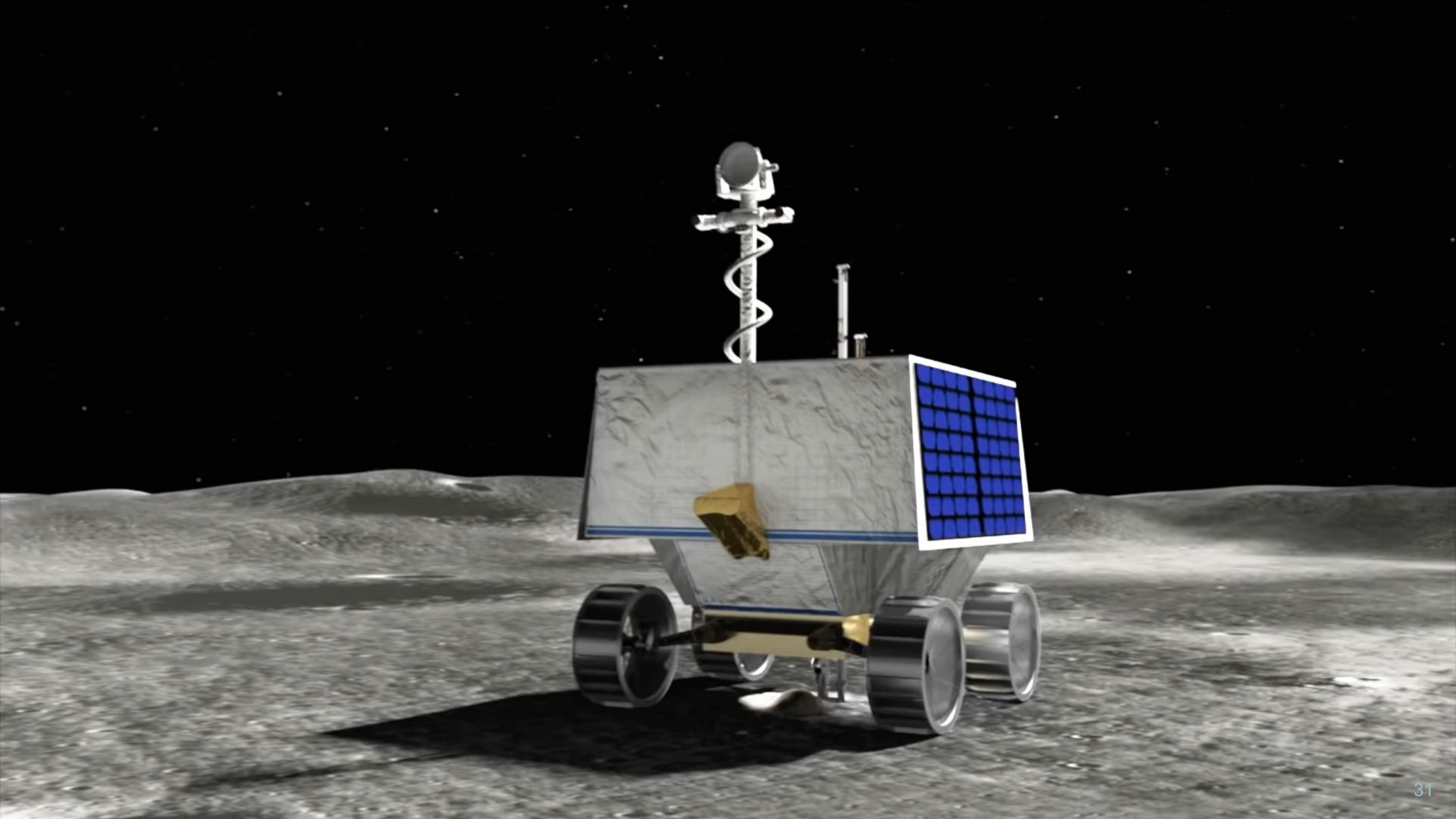
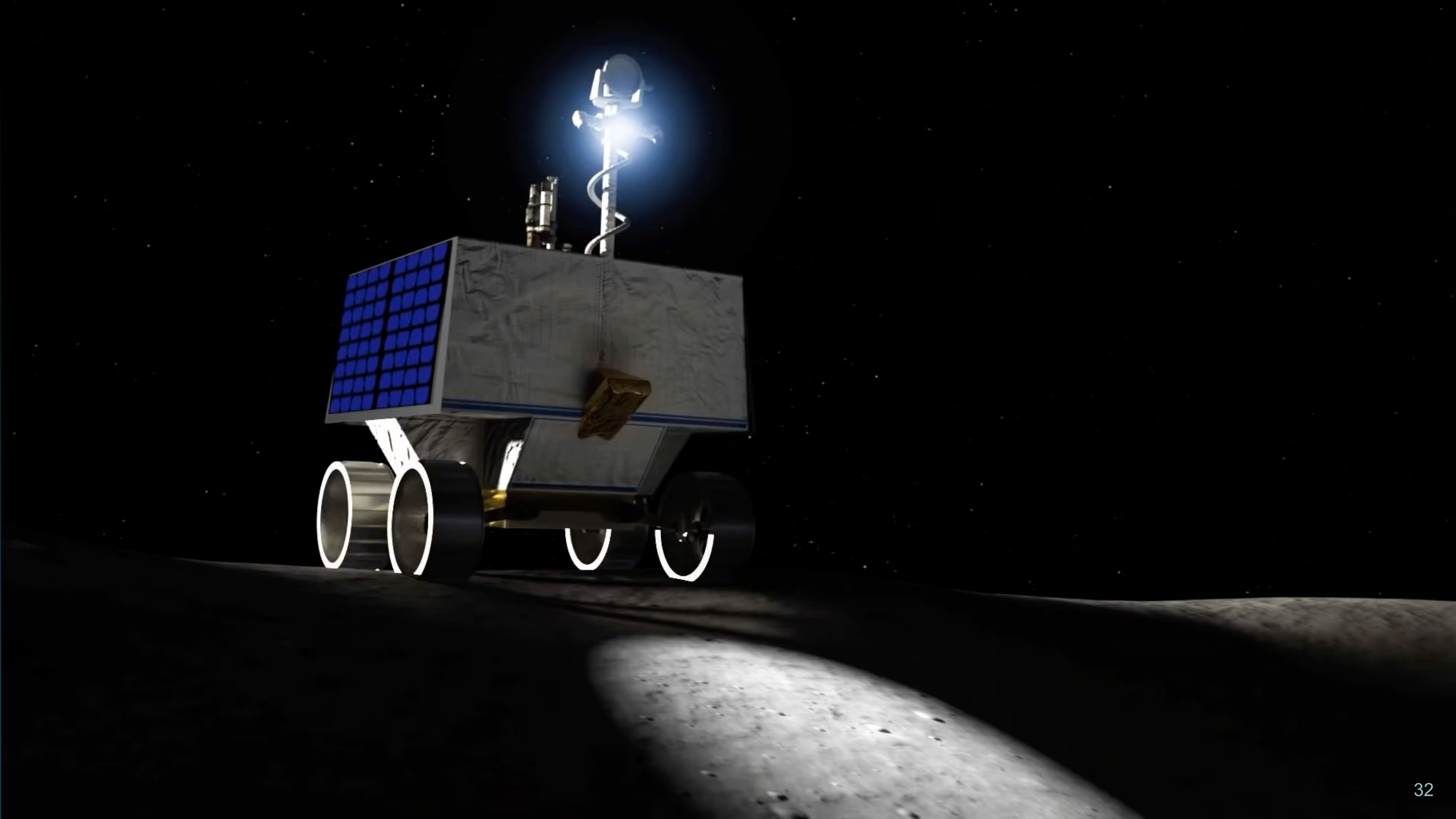
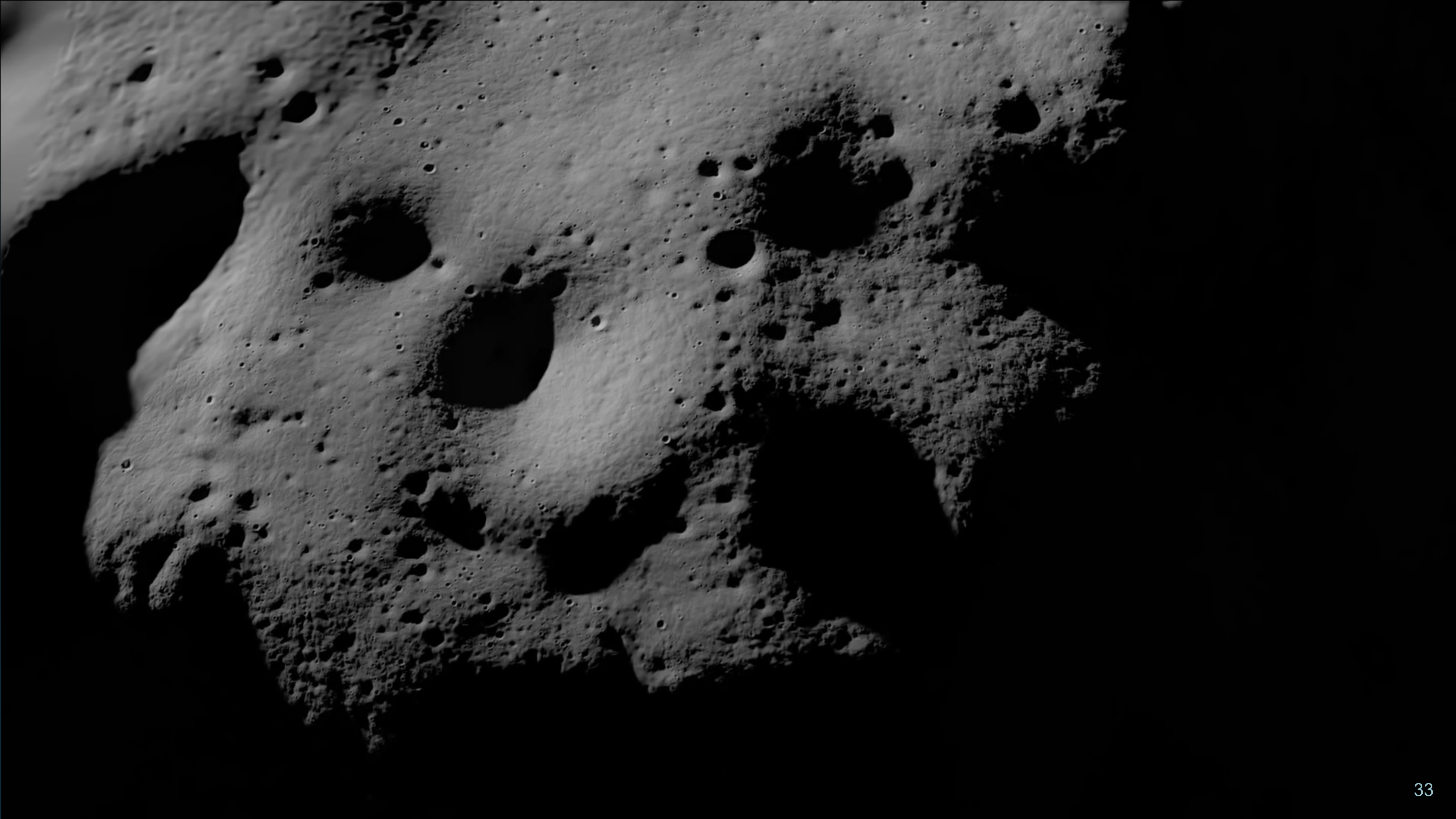


Image gallery

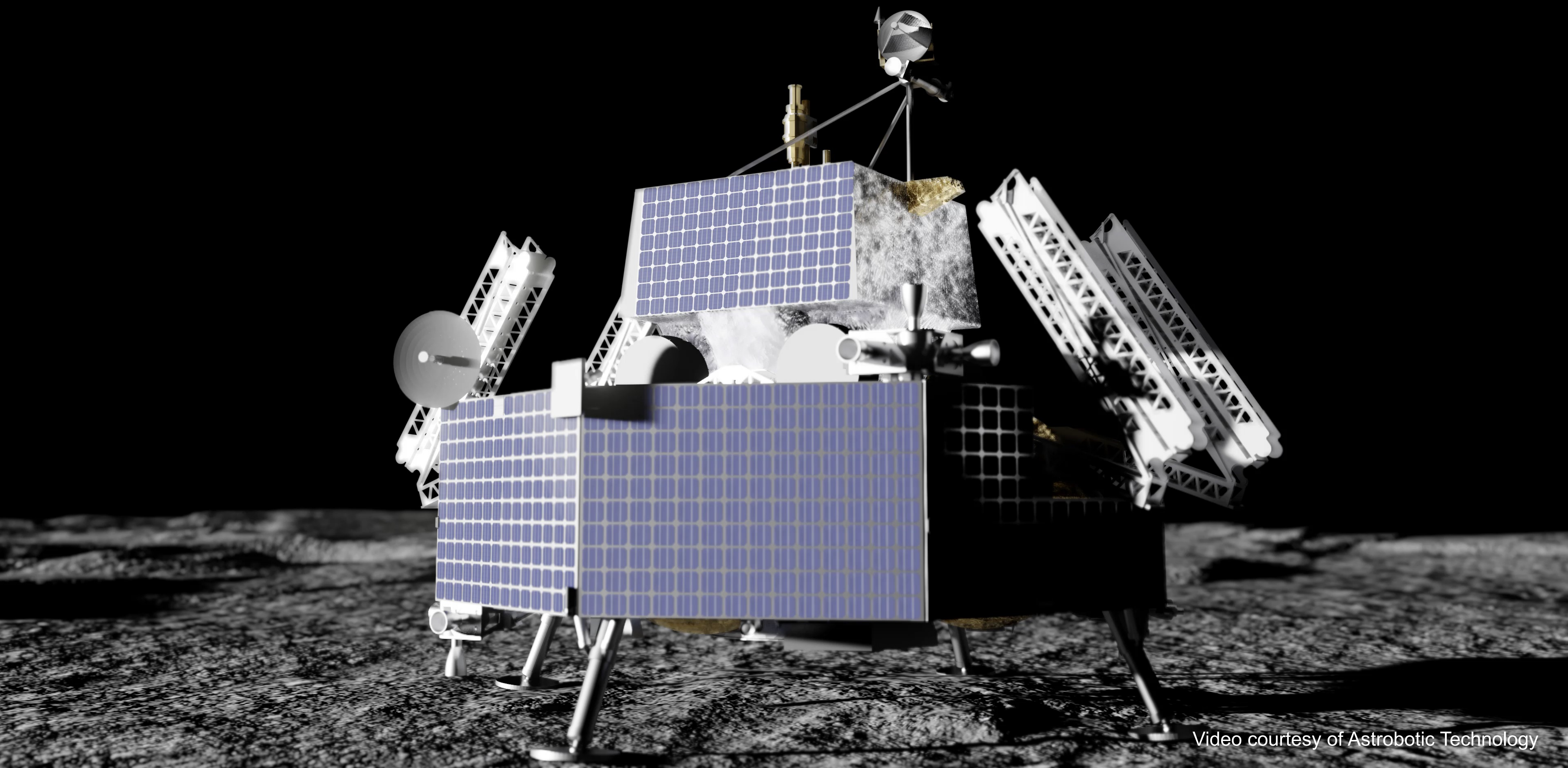

VIPER





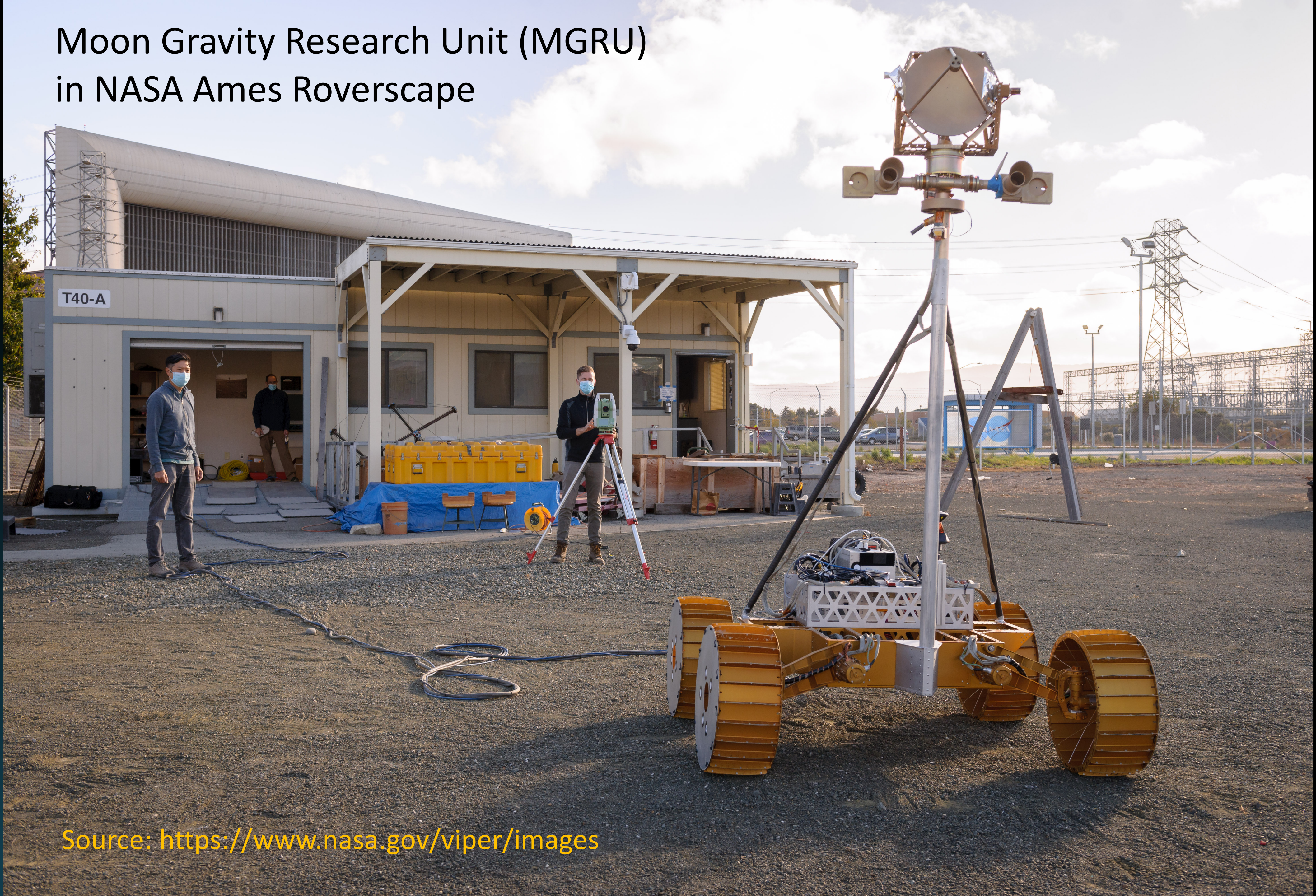


The NASA CLPS program has selected Astrobotic Technology, (Pittsburgh, PA, USA) for delivery of VIPER to the lunar South Pole in late-2023 aboard their Griffin Lander

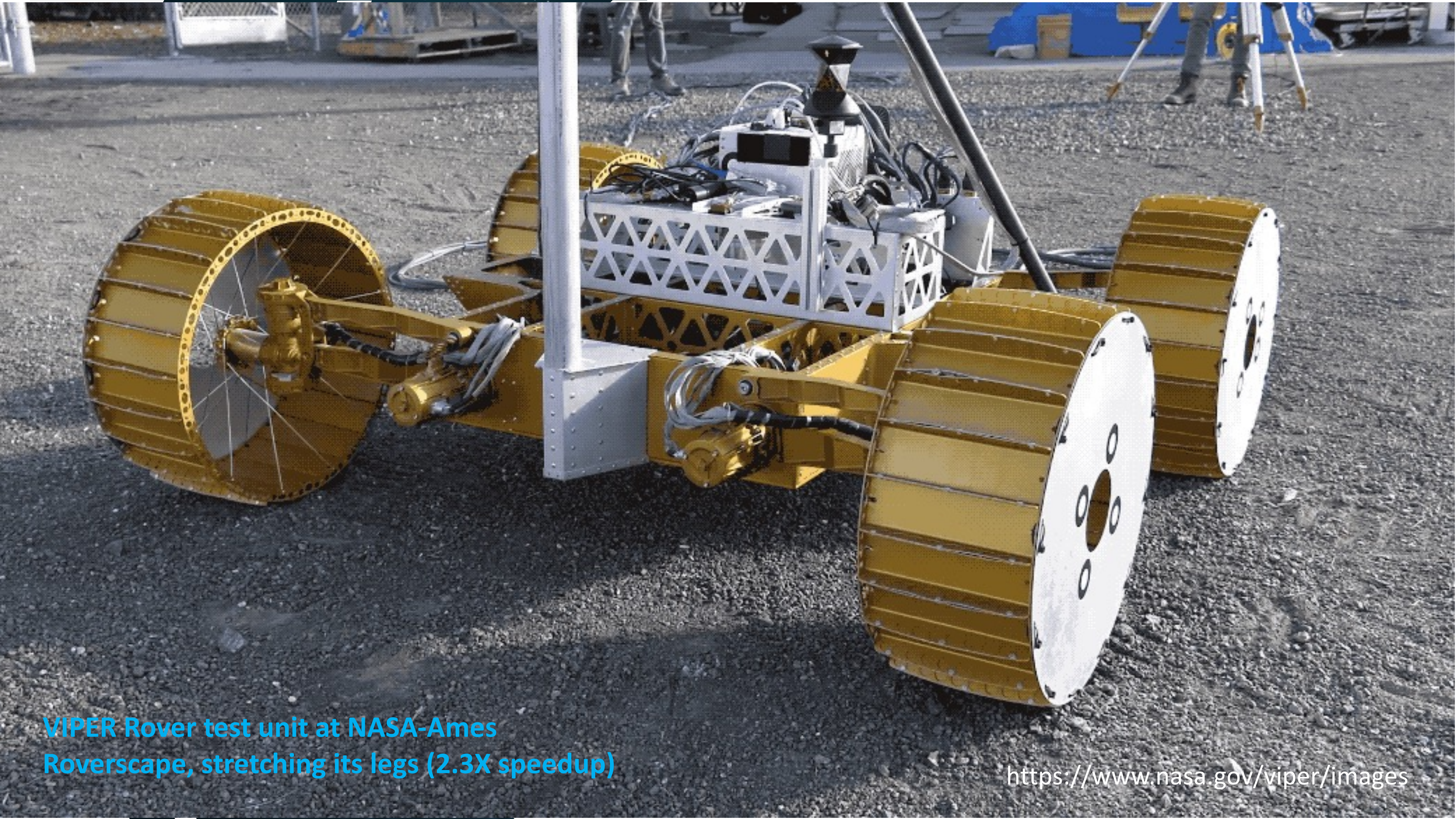


Video courtesy of Astrobotic Technology

Moon Gravity Research Unit (MGRU) in NASA Ames Roverscape

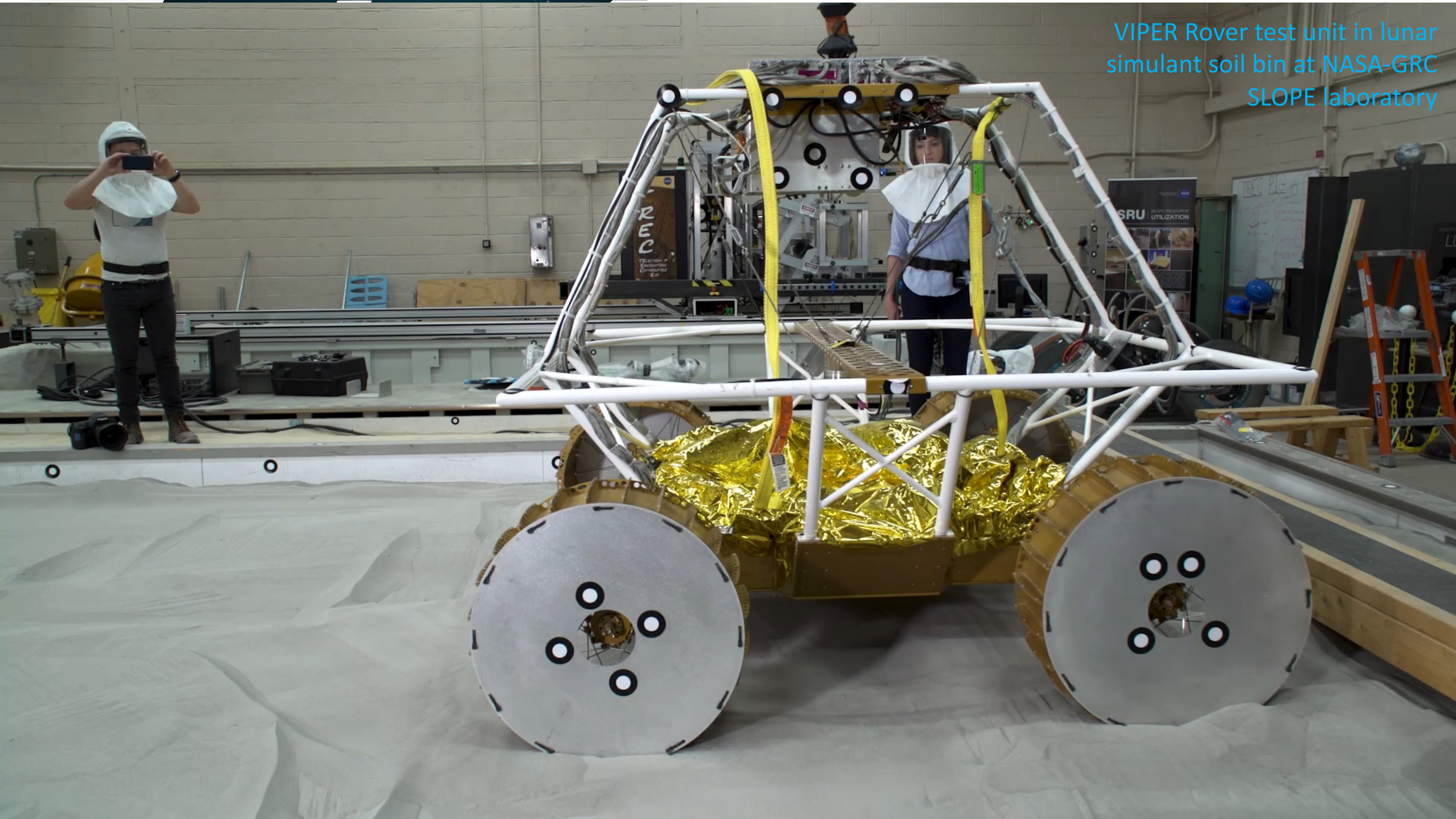


Source: https://www.nasa.gov/viper/images



VIPER Rover test unit at NASA-Ames
Roverscape, stretching its legs (2.3X speedup)

https://www.nasa.gov/viper/images



VIPER Rover test unit in lunar simulant soil bin at NASA-GRC SLOPE laboratory

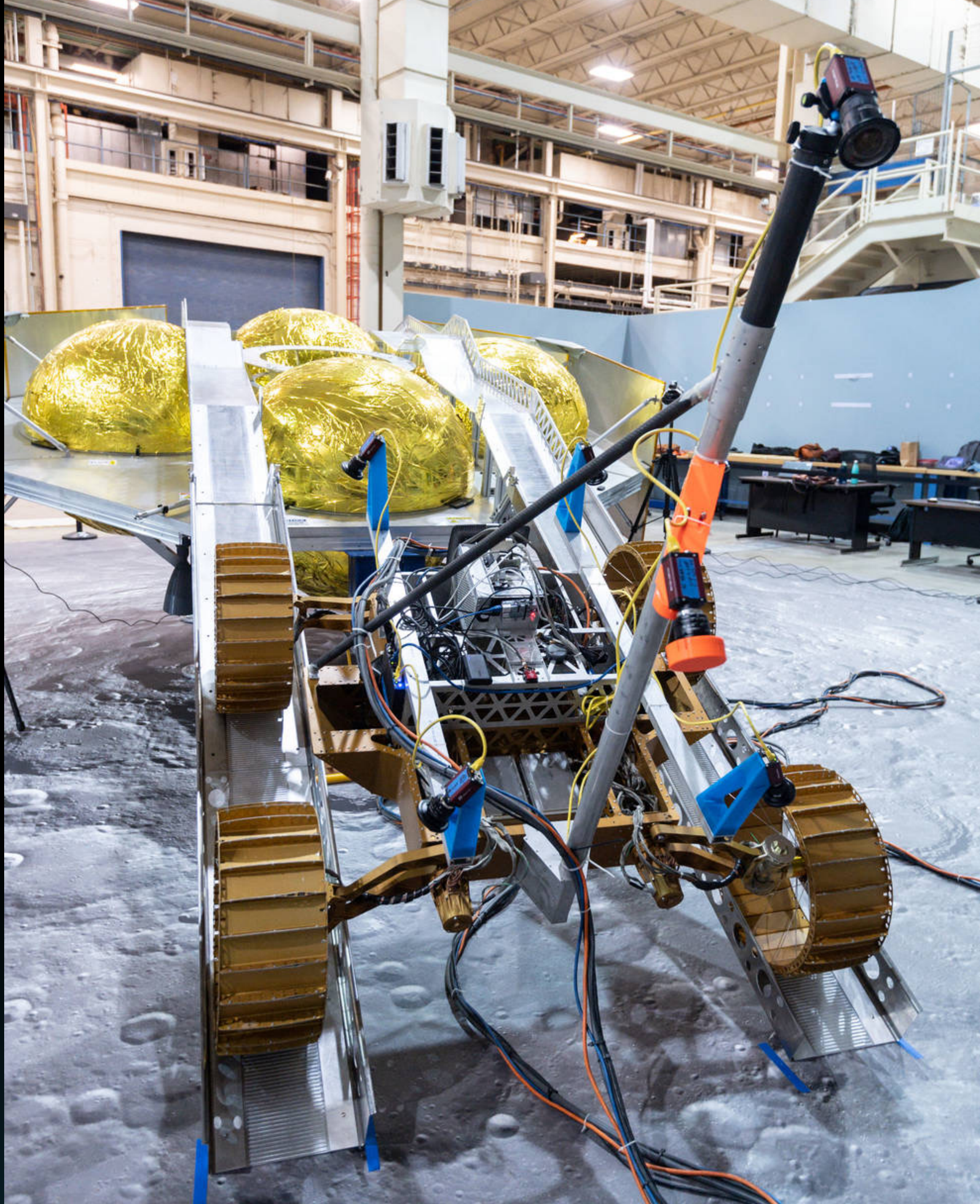
https://images.nasa.gov

Lander Egress Testing

MGRU 2.5 rover testing egress from Griffin Lander mockup

November 2021

https://www.nasa.gov/viper/images



Moon Water

The past decade of observations have built a fascinating and complicated story about lunar water.

From “frosts” to buried ice blocks, there appears to be water everywhere, but its nature and distribution is very uncertain.

The next steps in exploration require surface assets, including surface mobility.

VIPER is that mission to conduct exploration science, modeled after terrestrial resource exploration processes and techniques.

https://www.nasa.gov/viper

Launch Nov 2023

Questions?